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## *FINAL REPORT*

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# RE-ESTABLISHMENT OF A MIXED NATIVE GRASSLAND IN SOUTHWEST SASKATCHEWAN

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# 2005 Final report on reestablishment of a mixed native grassland in Southwest Saskatchewan (year four of a 4-year study)

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**Project Title:** Re-establishment of a mixed native grassland in Southwest Saskatchewan.

**Principal Investigators:** Drs. Alan Iwaasa* and Mike Schellenberg
Semiarid Prairie Agricultural Research Centre (SPARC)
Agriculture and Agri-Food Canada (AAFC)
P.O.Box 1030
Swift Current, SK., S9H 3X2
Phone: (306) 778:7251*

**Collaborative Investigators:** Dr. Robert Zentner, Dr. Brian McConkey and Mr. Keith Hanson
AAFC-SPARC

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## Abstract

This four-year research study clearly showed that it was possible to re-establish a mixed native grassland in southwest Saskatchewan without utilizing specialize seeding equipment. Simple and complex native species mixtures can affect animal grazing performances (0.60 vs. 0.76 kg $day^{-1}$) and C sequestration potential (2.53 vs. 1.48 Mg C $ha^{-1}$). Grazing disturbance did affect specie richness and how the native stand established, especially when compared to an ungrazed system. Results showed that the diverse native mix over time had similar or higher forage and beef production compared to the simple mix because of a niche complementarity among species. Higher than was expected C sequestration potential (2.12 Mg C $ha^{-1}$) was observed within the initial four-year period for the re-established native pastures. Date of seeding and seeding species by seral classification were beneficial for certain species (green needle grass, slender wheatgrass etc.) and are something to consider if future climate change scenarios of a drier environment for southern Saskatchewan occurs. The decrease in native seed costs, combined with the incentive programs, has improved the economic feasibility of establishing native pastures on marginal crop land. Unfortunately, the relatively short period of the study may have mitigated the detection of various treatment effects and future evaluation of this research study should continue.

## Executive Summary

Since the start of this research study a number of governmental programs have been initiated to encourage the conversion of annually cropped land to a more sustainable perennial cover (e.g., Saskatchewan Conservation Cover Program and the Federal Greencover Canada's Land Conversion) and more than 500 K ha of land in Saskatchewan has applied to be converted. Although a large percentage of this land will be seeded to tame forage species, a portion of the land will also be seeded into natives. It is also anticipated that Saskatchewan's cow herd over a 10-year time horizon could increase by 40%. This has already occurred due to the BSE situation that is affecting the Canadian livestock industry. Therefore, an increase in perennial pastures and forage management is needed to facilitate the current and future growth of the beef industry in Saskatchewan and in Canada. It is estimated that in western Canada (Alberta, Saskatchewan and Manitoba), between seven to 11 million ha of land is annually cultivated but are economically unprofitable and environmentally unsustainable (AAFC-PFRA 2000). It is recognized that native species are generally long-lived, contribute to a sustainable agricultural system and provide environmental benefits. Native species can also be useful for extending forage productivity and the grazing season into the late summer, fall and winter, therefore, large areas of native rangeland need to be maintained or rejuvenated and certain crop lands could definitely be re-seeded back to a native species.

Study results showed that a Bourgault disk air seeder was successful in seeding a native mixture of native species into standing stubble, however, careful monitoring of the seeding is needed to ensure a uniform flow of seed and prevent seed bridging problems which can result in skips and seeding misses. Of the fourteen grass, forb and shrub species seeded, only June grass (JG) and saltbush were not observed in the pastures during the seeding year, however, JG was observed later in following years. Wheatgrasses, green needle grass (GNG), needle and thread (NTG), blue grama (BG), little blue stem (LBS), purple prairie clover (PPC) were commonly observed in the seeding year. In contrast to previous research conducted at AAFC-SPARC, establishment of warm season grasses was not a problem. Effective pre and post-plant weed controls prior to seeding provided adequate weed suppression to promote successful native establishment past the 2001 drought period.

Study results found that the average soil organic carbon (SOC) level for the cultivated land (crop-fallow rotation for 80+ years) in 2000 was about 28 Mg C $ha^{-1}$ and in four short years under a native perennial grazing system about 2.12 Mg C $ha^{-1}$ was sequestered. This represents about 530 kg C $ha^{-1}$ $yr^{-1}$ being sequestered in the semiarid Brown soil area of the province. This is quite remarkable since average reported C sequestration rates for crop land converted to perennial grasses after 10 years have been 100 to 800 kg $ha^{-1}$ $yr^{-1}$. Clearly the favourable moisture received during the research study, producing good native forage biomass and the depleted level of SOC in the soil has greatly assisted in the amount of soil C that was sequestered. The simple native seed mix under high pasture utilization gave the highest ($P < 0.05$) SOC level compared to the other seed mixture and pasture utilization combinations. Higher SOC associated with the simple seed mix under high versus low pasture utilization treatments may be due to more livestock hoof action breaking down and incorporating the standing dead and litter into the soil and enhancing decomposition and reducing loss through oxidation. The generally higher SOC associated with the simple seed mixture can be mostly explained by the higher accumulation of biomass productivity (above and below ground) associated with the simple seed mixture, especially during the first year of pasture production, which would be a major factor influencing SOC production. In agreement, higher ($P = 0.01$) mean SOC values for the simple compared to the complex native seed mixture were found and the values were 2.53 and $1.48 \pm 0.83$ Mg C $ha^{-1}$, respectively. Mean SOC measurements did not differ ($P > 0.29$) between grazed and ungrazed treatments. These results are in contrast to a number of other research studies that have reported a benefit to grazing and higher grazing pressure on increasing soil C. However, it is too soon yet to determine potential SOC differences between grazing and pasture utilization treatments in the four years that have occurred. As expected, mean microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial dehydrogenase activity values were higher for treatments that corresponded to the higher biomass production and C sequestration levels. Results from this study shows evidence that the resident soil microbial population under a previous annual cropping system (80+ yrs) can continue to subsist and adapt and expand in a perennial native forage system quickly. Because the native pastures are still evolving and undergoing changes there is the need to further evaluate the microbial characterizations of the native soils in the future to determine their effects on SOC.

The highest forage production among the four production years was observed for the simple versus the complex seed mixture in 2002. This was expected since the wheatgrass species made up a higher proportion of the simple (i.e., 61%) compared to the complex seed mixture (30%). Unexpectedly available forage productions between the two native mixtures did not differ ($P > 0.05$) after 2003 and a steady forage production state may have been reached. Higher ($P < 0.05$) available forage yields were observed for the simple seed mix under low compared to high pasture utilization. Differences in grazing pressure and shifts in individual plant species due to grazing may provide another explanation for forage yields differences over the four years of production. The ability of the complex native mix to have forage yields that did not differ ($P > 0.05$) between the two pasture utilizations could be a result of the increase biodiversity existing in the complex pasture (i.e., cool and warm season grasses) and thus providing more flexibility in the plant community to adapt to the grazing treatments. Higher ($P < 0.05$) available forage production for the simple versus the complex native seed mix under a low pasture utilization was not surprising since the simple mix contained more aggressive and higher producing wheatgrasses while the complex mix contained other grasses with a slower onset of growth (e.g., warm season grasses).

All available forage quality measurements for the pasture studies were significant ($P < 0.0001$) for year effects. The wet and cloudy growing conditions and higher soil fertility observed in 2002 compared to the other years is a possible explanation for the lower % organic matter digestibility and higher % acid detergent fibre, % neutral detergent fibre (NDF) and % crude protein observed. Higher ($P < 0.05$) NDF value was observed for the complex versus the simple seed mixture while all other forage quality's measurements did not differ for forage biomass harvested just before the cattle started grazing (i.e., spring season). However, better nutritional forage qualities for the complex versus the simple native mixes were observed as the grazing season extended into the summer and fall season.

Significant ($P < 0.0001$) year effect occurred for average daily gain (ADG) and total live production (TLP) and year 2003 had the lowest ($P < 0.001$) ADG and TLP values compared to the other two years (2002 and 2004). The ADG values for 2002 and 2004 were similar, while the TLP value for 2004 was the highest ($P < 0.05$) due to the favourable moisture condition and extended grazing season that occurred. Although not significant ($P = 0.12$), the overall ADG mean for the complex mix was higher than the simple mix. These results correspond to about a 26.6% overall improvement in ADG for yearling steers grazing on the complex compared to the simple native pastures through the grazing season. It is plausible to expect better steer grazing performance on the complex pastures due to the higher specie richness (i.e., different mixture of warm and cool season grasses and shrubs) that would improve the nutritional composition of the pasture through the entire grazing season (spring to fall). The trend ($P = 0.14$) for higher ADGs for steers grazing at the higher compared to the low pasture utilization level was also observed, which was probably due to higher degree of forage selection and regrowth potential. Throughout the research study, different grazing behaviours for the yearling steers were observed on the different native pastures throughout the grazing season. During the spring and early summer period of grazing the cattle have no difficulty grazing and selecting for Canadian wildrye grass (CWR), awn wheatgrass (AWG), slender wheatgrass (SWG), NTG, GNG, northern wheatgrass (NWG) and western wheatgrass (WWG) species. Once the grazing period reached mid summer and many of the cool season grasses were at heading and seed setting the steers on the complex native pasture selectively grazed the warm season grasses, PPC (even at the heading/seed stage) and regrowth areas from cool season grasses. In the fall grazing season, cattle continued to select for warm season grasses, however, once heading and seed setting had occurred the steers grazed these grasses less and less and appeared to start grazing NTG, GNG, NWG and WWG. Fall grazing preference of the warm season grasses in our study was observed to following this ranking LBS ≥ PSR > BG. The observed grazing preferences shown by yearling steers for our research studies are very much dependent upon what plant species are available for them to choose from and the grazing management.

The 2004 data for the large pastures continues to indicate the grazing impact on species richness. Grazed vegetation had greater diversity than the ungrazed. The species within the ungrazed are changing but continue to be dominated by the wheatgrasses. NWG decreased in dominance while WWG increased. Northern wheatgrass and SWG appear to function as early seral species with an initial flush with eventual replacement with slower growing later seral species, in this case WWG and LBS. Purple prairie clover also increased over time. Wheat grasses made up 97% of the composition of the simple mix but only 66% of the complex mix. There was an increase in the warm season grasses, BG and LBS, and PPC. This may have been in part due to the more open canopy due to grazing. Weed content was insignificant after three years.

The date of seeding effects were evident throughout the three years of growth for both small plot studies. Green needle grass contributed more to the plot composition throughout all years if seeded in late fall. Slender wheatgrass showed a similar trend but only when seeded in early spring. The hot dry year of 2003 greatly decreased establishment for both small plot studies. The seral stages studies clearly demonstrated the advantage of fall seeding for all species. This result is something which should be considered if future climate change scenarios, which indicate a drier environment for southern Saskatchewan, are valid.

Both small plot studies showed an increase in similarity with minor changes in species richness. These changes possibly reflect the impact of the single fall harvest regime. This single fall harvest allowed the wheatgrass to out compete the slower growing species closing the canopy. Species richness is also less than values calculated for the grazed pastures further indicating the benefit of grazing disturbance in retaining species diversity.

The ungrazed enclosures in the pastures do not show the same trend seen in the small plots. In the ungrazed enclosures there is an increase in rhizomatous species, western wheatgrass and little blue stem. This may reflect the impact of having a grazing disturbance immediately adjacent to a relatively small ungrazed remnant. Grazing may increased the competitive advantage of the rhizomatous species outside the enclosure resulting in an invasion of the area within the enclosure by these species.

Seeding species by seral classification affects certain species. Northern wheatgrass, GNG and SWG appear to benefit from seeding in this fashion. Other species may benefit but the strongly contrasting environmental conditions between years may have concealed any potential benefits.

The decrease in native seed costs, combined with the incentive programs, has improved the economic feasibility of establishing native pastures on marginal crop land. In doing this, there is no greater risk in establishment or production, compared to other tame species that have historically been favored for this type of seeding. Overall, our economic analyses suggest that the most profitable pasture system was MBr-alfalfa for grazing both steers and cow-calf pairs, but with RWR-alfalfa being a close second. The complex native mix pasture system when used for grazing steers at a high stocking rate was approximately economically competitive with RWR monoculture (when one includes the incentive programs), but it was not generally economically competitive with the tame grass-legume mixes. And for cow-calf pairs, our results suggest that the simple native mix at the low stocking rate was typically more profitable than the monoculture tames grass pastures and CWC-alfalfa, and was generally comparable in net earnings to alfalfa alone. Other potential benefits from environmental sustainable agricultural practices (C sequestraton/C credits, environmental farm plan etc.) may also provide financial incentives that would see more annual crop land converted into native pastures.

## Glossary and List of Abbreviations

ac = acre
ADF = acid detergent fibre
ADG =daily gains kg/day
AU = animal unit (based on one mature 450 kg cow or the equivalent based upon average daily forage consumption of 11.8 kg)
AWG = awn wheatgrass
BG = blue grama
$C_3$ plant = A plant employing ribulose bisphosphate carboxylase as the primary $C0_2$ capturing enzyme, with the first product being a 3-carbon acid
$C_4$ plant = A plant employing phosphoenolpyruvate carboxylase as the primary $C0_2$ capturing enzyme, with the first product being a 4-carbon acid
cm = centimetre
CP = crude protein
CWG = crested wheatgrass
CWR = Canadian wildrye
d = day
DM = dry matter
fig = figure
g = gram
GD = grazing day (total number of animals x days on test)/area)
GNG = green needle grass
h = hour
ha = hectare
JG = June grass
K = potassium
kg = kilogram
LBS = little blue stem
m = metre
MBC = microbial biomass carbon
Mbr = meadow brome
Mg = mega gram
mm = millimetre
N = nitrogen
NDF = neutral detergent fibre
NTG = needle and thread grass
NWG = northern wheatgrass
OM = organic matter
OMD = organic matter digestibility
P = phosphorus
pasture utilization = refers to the percentage of the annual production of forage that has been removed by animals throughout a grazing period (low = 40-50% and high = 60-75%)

PLS = pure live seed
PPC = purple prairie clover
PSR = prairie sandreed grass
RWR = Russian wildrye
S = sulfur
SMD = soil microbial dehydrogenase
SOC = soil organic carbon
stocking density = the relationship between number of animals and area of land at any instant of time, or grazing management unit utilized over a specified time period (low = 2 steers or 1.3 AU per ha and high = 4 steers or 2.7 AU per ha)
SWG = slender wheatgrass
TLP = total live production (average daily gain x grazing days per hectare)
WF = winter fat
WWG = western wheatgrass
yr = year

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## Introduction

It is recognized that in the last 150 years, large changes have occurred in the central grassland ecosystems due to agriculture expansion and urbanization. Currently it is estimated that the mixed and short grass prairies in North America have been reduced to 20 to 30% of their former extent. This is evident in Saskatchewan, where it is estimated that more than 80% of the prairie has been lost and in areas of prime crop land, less than 2% of the original native prairie remains (Gauthier et al. 2003). As the native prairie reduces in size there is an increase likelihood that fragmentation of the native habitat caused by urban development, oil and gas extraction and agricultural practices will occur. Since the majority of the remaining native grassland in Saskatchewan occurs on range and pasture lands, any strategies to prevent further reduction of this land base or the ability to increase native range and pasture lands would be beneficial to preserving and improving our native prairie resource.

Ranching and livestock production has helped to protect the prairie against fragmentation because ranchers need large blocks of land for their cattle (Gauthier et al. 2003). Since native prairies have evolved under such natural disturbances as fire, drought and grazing, it should not be surprising that domestic livestock grazing appear to be a sustainable use of Northern Great Plain grasslands. Research studies (Milchunas et al. 1988; Lauenroth et al. 1994; Bai et al. 2001 and 2005) have reported that proper grazing management by domestic livestock has minimal or no adverse effects on plant community or soil characteristics, and in some cases, grazing by ungulates may help with nutrient cycling and plant diversity. However, the potential effects and benefits of grazing by domestic cattle have not always been consistently observed and this can be explained by differences in grazing intensity, evolutionary history of the site and climatic regimes. Milchunas et al. (1990) concluded that plant communities that have co-evolved with large herbivores for thousands of years before domestic grazers were introduced will more likely have a negative response to the removal of grazers rather than to grazing by domestic livestock as has been demonstrated for the short grass steppe ecoregion.

The largest prairie ecoregion in Saskatchewan is the mixed grassland. The native vegetation in this ecoregion is often referred to as “short grasses” (blue grama grass and June grass) and “mid to tall grasses” (wheatgrasses, needle-and-thread, and porcupine grass), along with pasture sage and club moss. The balance between mid and short grasses varies with climate, soil and grazing pressure. More than 50% of the remaining native grassland in Saskatchewan occurs in the mixed grassland ecoregion. About 31% of the land area is occupied by native grassland and 62% is cultivated. Large areas of the mixed grassland are uneconomical for crop production due to poor soils and hot and dry environmental conditions. As a result of this ranching and livestock production plays a significant role in conserving and managing the prairie ecosystem and contributing to the rural and provincial economy (Saskatchewan PCAP 2003). As more cultivated crop land on the Brown Chernozem soil zone becomes economically marginal due to changing market conditions, the growing of forages (tame and native) for cattle grazing and forage production on such land becomes more attractive. Over the last decade, there has been a renewed and growing interest in native plant species in Canada resulting in a number of public, industry and government (i.e., Saskatchewan Conservation Cover Program and the Federal Greencover Program) initiatives to preserve, maintain and even increase the amount of land containing native plant species. In Saskatchewan, it is estimated that about 110,000 ha (275,000 ac) of land will be converted to forages as a result of the Greencover Program. Although, not all the acreages will be seeded to native, a portion will be, therefore research and technical information on how to best establish and utilize the native forage/pasture resource will be needed. Restoring land back to the original biodiversity of the mixed prairie (i.e., containing several hundred species of grasses, forbs and shrubs) may not be possible, however seeding a few available native species mixtures that have good potential animal utilization and yet also provide improved ecological biodiversity and environmental benefits may be the next best thing. Tilman et al (2001) found within plots located in Minnesota that biodiversity increased plant community productivity and provided greater adaptation to climatic variation. Diverse mixes having species which mature at different times throughout the growing season also have the potential to provide nutritional quality desirable for livestock and wildlife maintenance and production over a greater portion of the growing season than a monoculture (Cook 1972; Wilson 1982; Jones and Wilson 1987).

Aside from the importance that native prairie grasslands play as a repository for biodiversity, wildlife habitat and providing a grazing resource, the restoration and maintenance of native prairie grasslands can provide an important opportunity to mitigate greenhouse gas concerns through soil organic carbon (SOC) sequestration. Sequestration of SOC is influenced by a variety of factors that include: climate > vegetation > topography = parent materia l> age, all of these soil forming factors contribute to the C content in soils. Since all of these factors are highly variable SOC amounts are also highly variable. Soil Organic Matter (SOM) is closely related to SOC levels and practices that increase SOM also increase SOC. Bruce et al. (1999) summarize the leading causes of decreases in SOM to include degradative processes such as erosion, compaction, breakdown of soil structure, and mineralization or oxidization. These processes are started by activities such as tillage, biomass burning, drainage of wetlands, improper grazing, and mining of soil fertility by poor agriculture practices. Management practices have been shown to influence C sequestration of rangelands. Grazing, burning, and fertilization have all been proven to increase soil C storage in rangeland soils of the Northern Great Plains (Mortenson et al. 2002). In order to increase SOM, one must increase the amount of C entering the soil as plant residues and reduce soil degrading processes or suppress the rate of soil C decomposition (Bruce et al. 1999). Dormaar (1989) and Dormaar et al. (1995) found that the qualities of SOM in native grasslands were superior to that occurring in soils under cultivation and under certain introduced grass species (e.g., crested wheatgrass). Soil organic carbon in rangeland soils may exceed all above-ground portions of a temperate forest and this amount can be increased by returning previously cultivated land back into grasslands. In addition, higher SOC has been observed for rangeland under good grazing management versus under an ungrazed treatment, thus grazing management may offer a very practical option for increasing SOC (Janzen et al. 2000).

Little research has been conducted on agricultural land to re-establish a more native prairie ecosystem in Saskatchewan and determine this land's C sequestration potential. Most plants seeded for use as forages have been seeded as monocultures or as binary mixtures. The binary mixture is typically a grass and legume. Often these seeds for forages are tame agronomic species with general seeding recommendations. Baskin and Baskin (2005) identified the majority of native plant material has some form of dormancy which may be combined with seed structures needed for dispersal, emergence or burial. Establishment recommendations for agronomic species, which have been selected for easy seeding, rapid emergence and germination, may not be applicable for many native species. These possible differences between agronomic and native species combined with dynamics found within native plant communities also suggest simply seeding all species at the same time may not result in a plant community containing all the seeded species. Hammermeister and Naeth (1999) demonstrated the ability of wheatgrasses to out compete other plant species and dominate plant communities. This domination eventually results in some single species plant communities. A more natural means would appear to be to seed plant species in a sequence which is similar to how they occur during secondary succession. Small plot experiments were initiated within the study "Re-establishment of a mixed native grassland in Southwest Saskatchewan" to address these questions.

Large knowledge gaps exist on the production potential of seeded native species and C sequestration potential under various grazing intensities (none, low and high). Many cattle producers have considered and are interested in the better use of existing native rangeland and the potential of reseeding native species on land for summer, fall and winter grazing options (Iwaasa et al. 2002; Iwaasa and Schellenberg 2005; Jefferson et al. 2005). Saskatchewan alone has about five million ha (12.5 million ac) of native range and it is anticipated that additional land will be seeded to native species. Therefore, the need for research information on how to best re-establish native species on agricultural land under grazing was identified and a new research study was initiated at AAFC-SPARC in 2001.

## Project Objectives

1. Evaluate animal performance and environmental benefit difference between two native seed mixtures (simple and diverse mixtures);
2. Evaluate the impact cattle grazed (low and high stocking rates), ungrazed (enclosures) and seed mixtures have on native stand establishment and long term stability of the plant community, plants/species diversity, forage production and microbial and biochemical properties of the soil;
3. Evaluate the opportunities grazing management may provide to increase carbon sequestration potential of a perennial native pasture vs. annual/fallow crop rotation;
4. Develop a management plan that determines the cost/benefit of re-introducing a perennial native pasture back on land that has been annually cropped;
5. To evaluate the effects that optimum 'date' of seeding, moisture levels and seral adaptation of the species have on establishment characteristics.

## Materials and Methods

### *Fall of year 2000 on the large pasture study*

The 65 hectares (160 ac) have been cropped since the 1920's and in 1995, Agriculture and Agri-Food Canada (AAFC) for the Semiarid Prairie Agricultural Research Centre (SPARC) acquired the land and continued to grow cereal crops on the land annually. Soil classifications of the land are mostly Swinton orthic brown chernozems with some Haverhill soils occurring on the knolls and convexities near runways. Soil texture is largely silt loam for the Swinton soils but usually is loam on the Haverhill soils. The Swinton is a class three soil while Haverhill loam is class four. About 32 hectares (80 acres) were utilized for the large pasture research study. Prior to the start of the research study the land was seeded into barley and harvested as green feed in July to minimize the presence of volunteer cereals in the planting year. In September the research land was sprayed with Roundup Renew 2.5 L per ha (0.22 gal per ac) for perennial and annual weed control.

### *Year 2001 large pasture study*

#### *Seeding of the large pasture study*

Roundup Renew was applied at 3.75 L per ha (0.33 gal per ac) on the entire research pasture on May 6 for annual and perennial weed control. Four days after the herbicide treatment was applied, eight pastures were seeded to a simple mixture and another eight pastures to a complex seed mixture using a Bourgault double disk air seeder. All seed mixtures were formulated by Native Plant Solution - Ducks Unlimited Canada (NPS-DUC) for this study, therefore, the percent of each seeded specie in our mixes are proprietary information of NPS-DUC (seed mixtures refer Appendix 2). Seeding was done into the weed-free standing stubble. This technique can be especially valuable in drier areas where the snow-catch in the stubble can improve surface moisture condition and assist seed germination. The seeding rate for the simple mixture was 9.5 kg $ha^{-1}$ (8.5 lb $ac^{-1}$ and 25 pure live seeds per $ft^2$) using a 22.5 cm (9 in) row spacing and seeding depth of about 6.2 mm (0.25 in). To facilitate the seeding, 18 kg $ha^{-1}$ (16 lb $ac^{-1}$) of 11-51-00 fertilizer was used as a seed carrier to prevent seed bridging. The complex seeding mixture was 9 kg $ha^{-1}$ (8 lb $ac^{-1}$ and 33 pure live seeds per $ft^2$) using the same row spacing and seeding depth and about 34 kg $ha^{-1}$ (30 lb $ac^{-1}$) of 11-51-00 fertilizer was used as a carrier. Further weed control (e.g., flixweed) on the 16 pastures in July was required and 1 L per ha ( 0.088 gal $ac^{-1}$ ) of Buctril M was applied and provided effective weed control with no apparent damage to the native seedlings. Some of the pastures also had wild oat weed concerns, therefore these pastures were mowed and green material hauled away to reduce plant competition and prevent the wild oats from forming seed heads. Fencing of the 16 pastures commenced in August and was completed in October. The very dry conditions of 2001 necessitated the need to aerial spray Decis insecticide 0.15 L per ha (0.0132 gal $ac^{-1}$) in September to control grasshopper infestation. In November two shrubs, winterfat and saltbush, were seeded using a hand-held broadcaster at a rate of 11.75 pure live seeds per $m^2$ onto the complex seeded pastures.

### *Year 2002*, **2003 and 2004** *large pasture study*

#### *Assessment of seeding success and pasture reseeding*

Successful stand establishment was estimated using density or plant count measurements within a standard 0.3 $m^2$ (1 $ft^2$) quadrat (Wark et al. 1995). Ten samples were taken per pasture (2.1 ha in size) which is higher than the standard recommendation of one sample per half hectare (Wark et al. 1995). Due to some herbicide spray misses in 2001, small portions ($\leq 5\%$) of five pastures (2, 4, 5, 6 and 8) were re-seeded. In addition, about 7% of pasture one was re-seeded due to salinity problems and about 50% of pasture seven was re-seeded due to seeding problems (i.e., bridging) in 2001. Reseeding was done at the beginning of May using a 3.3 m wide press disc seeder with 30 cm row spacing and attached to a three-point hitch.

#### *Pasture production and grazing performance*

The spring of 2002 appeared to be a repeat of the 2001 drought year that was experienced in southwest Saskatchewan (Appendix 1). It is well accepted that spring (April, May and June) moisture is essential (Jefferson 2002) for normal forage production to occur, therefore a decision was made to reduce the SPARC cattle herd. This reduction in beef cattle numbers required that the number of steers originally allocated to the native establishment study be reduced from 96 to 80 steers. Although the two target pasture utilization levels, low (40-50%) and high (60-75%), would remain the same, the stocking rates were modified. The planned stocking rate for the low utilization was four steers per pasture (@ 1.3 AU $ha^{-1}$ or 0.5 AU $ac^{-1}$) and the high was eight steers per pasture (@ 2.7 AU $ha^{-1}$ or 1.1 AU $ac^{-1}$). The higher stocking rate was reduced to six steers per pasture (2.0 AU $ha^{-1}$ or 0.8 AU $ac^{-1}$) in 2002. In 2003, a total of 96 steers were utilized in which the stocking rate returned to the original design in which the low utilization used four steers per pasture and the high used eight steers per pasture.

In 2002 80 Red Angus grazing steers (346 ± 21 kg) were used, while in 2003 and 2004, 96 Hereford (346 ± 19 kg) and Red Angus (333 ± 18 kg) grazing steers were utilized, respectively. In 2002, groups of four and six steers were randomly allocated, while in 2003 and 2004, groups of four and eight steers were selected randomly. Each group was blocked according to body weight, making the average body weights for all groups similar. Pasture treatments consisted of a 2 x 2 factorial experimental design with four replications: two pasture seed mixtures (simple and complex) and two grazing utilization levels [low (40-50%) and high (60-75%)]. A total of sixteen pastures, each 2.1 ha (5.2 ac) in size, were utilized for this research study. In 2003 and 2004, eight pastures contained eight steers each (total 64) while in 2002 those same pastures contained six steers each (total 48 steers). Of those eight pastures, four pastures were grazed at the low utilization level and the other four pastures were grazed at the high utilization level. Similarly, in 2002, 2003 and 2004, the remaining eight pastures each contained four steers (total 32 steers) and four pastures randomly allocated to either a low or high grazing utilization levels. Before the grazing season started, four movable pasture cages, each 0.9 x 1.5 m in size, were randomly distributed on each pasture to measure peak pasture forage yields for the season (Cook and Stubbendick 1986). Because the pasture sward consisted mostly of cool season grasses with various proportions of other species (i.e., warm season grasses, legume etc.), forage qualities were taken in June/July, August and again in September. In addition to the four pasture cages that are moved each grazing season, each pasture also contained a permanent grazing enclosure (3.6 x 3.6 m) located near the middle of each pasture. This larger enclosure was totally excluded from any cattle grazing and represented an ungrazed treatment. Estimations of available yields were determined using a procedure from Cook and Stubbendick (1986) in which representative $m^2$ quadrat samples were taken near each of the four pasture cages. Native and weed plant material was separated for each sample and dry matter (DM) production and forage quality analyses were conducted. Initially, four samples were taken per pasture but this was increased to eight to address sample variation concerns. For all three years, all steers were initially weighed after a 12 h shrink prior to being placed on the pastures. In 2002 the steers were placed on the native pastures on July 4, in 2003 on June 20 and in 2004 on June 24. At the time of grazing the prominent grasses (e.g., SWG, NWG, WWG, AWG, NTG etc.) were either at the boot or early heading stage of maturity. For all three years, after the steers were initially placed on the pastures, weighing periods occurred throughout the study every two to three weeks, in which the steers were weighed and a five percent shrink (based on previous research experiences) was used. Once the pasture utilization level for each pasture was achieved based on visual estimation, the steers were removed from the pasture and weighed after a 12 h shrink. The grazing period for some steers lasted from June to the end of September. In 2002 some steers remained on pasture till Sept. 5, in 2003 till Sept. 30 and for 2004 till Sept. 20. Cattle performance measurements were used to calculate average daily gains (ADG) in kg $d^{-1}$, total live production (TLP) in kg $ha^{-1}$ and grazing days (GD) $ha^{-1}$. Residual pasture yields for each previously grazed pasture were determined using a $m^2$ quadrat to accurately determine pasture utilization after the steers were removed (Cook and Stubbendick 1986).

### *Determination of species composition of large pastures in 2002, 2003 and 2004*

For all years species compositions were done using a diagonal transect with 10 sampling sites per pasture using a 1/4 $m^2$ frame. Clippings were taken in areas adjacent to the transect sampling sites but not in them. Plant material within this quadrat was harvested to a height of 2.5 cm from the ground and these clippings were used to determine peak yields. Native and weed plant material were separated, dried, and composited (10 samples). Forage quality analyses were determined for weed and native forage samples. In 2002, plant species composition for each of the sixteen pastures was evaluated from Sept. to the beginning of October. In 2003, due to the extreme dry condition in the summer period (July and August) the plant identification took longer than anticipated. This resulted in only 2 replicates being done and the enclosures were missed on all of the large pastures. The early and large first snow fall that started on Oct. 28 and lasted till Nov. 6 dramatically affected the ability to conduct the species composition measurements as normally planned and the botanical compositions were called to a halt. In 2004, plant compositions were done from Aug. 5 to Sept. 8. In an effort to ensure all compositions were completed in a timely manner only five of ten sample points per pasture were sampled. The five sampling points were selected randomly from the ten permanent sampling points.

### *Forage analyses*

Forage quality analyses were performed on all pasture samples (i.e., available yields, specie compositions etc.) from 2002 to 2005. All forage material was dried in a forced air oven for 48 h. Samples were ground through a 1 mm screen Wiley mill grinder. Percent organic matter (OM), organic matter digestibility (OMD), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and minerals, nitrogen (N) and phosphorus (P) were determined using Standard Operating Procedures Forage Laboratory (2001).

### *Soil sampling and analyses*

#### *Total soil organic carbon, microbial biomass carbon and soil microbial dehydrogenase*

Sampling from each of the sixteen pastures started in the fall of 2000. Prior to soil sampling all surface residues in the area where the soil samples would be taken were cut and the soil surface flattened. Soil from each pasture was sampled from five different locations and these sites were permanently marked for future sampling. At each site location, core (6.3 cm cutting edge diameter) samples were taken at six micro-sites and at four depths (0-15, 15-30, 30-45 and 45-60 cm). In 2000 a total of 1920 soil samples were taken and all of these samples were used for SOC determination. Soil core samples from only the first depth were used in the determination of soil microbial biomass carbon (MBC) (total of 480 samples taken). In 2004, once again all sixteen pastures were soil sampled in the fall, however, after the initial analysis of the 2000 SOC it was determined that overall variations within pastures were low enough that only three of the five sites within each pasture needed to be sampled and that at each soil depth from each micro-site could be pooled. Thus, at each site location (only three locations per pasture), core samples were taken at five micro-sites and at five depths (0-7.5, 7.5-15,15-30, 30-45 and 45-60 cm). In 2004 a total of 160 soil samples were taken, however only the top three depths were used for SOC determination (120 samples). Soil core samples for MBC under different grazing treatments were taken from four site locations per pasture and for the first two depths at all five micro-sites. Core samples from each micro-site depth were pooled. Soil core samples for MBC under an ungrazed treatment were taken from eight random pasture enclosures, five micro-sites and at two depths. Total number of soil samples taken for MBC for grazed and ungrazed treatments were 144. All soil samples taken in 2000 and 2004 were bagged at each depth and initially stored at +2$^0$C until a time was available to further sieve the soil samples and prepare them for SOC and MBC analyses.

The soil processing of the 2000 and 2004 samples for SOC consisted of determining a fresh gross weight of each sample and then taking a sub-sample to determine moisture content. Soil bulk density for each soil sample was determined based on the fresh gross soil weight and moisture content. Sieving process consisted of taking the soil sample and sieving it through a 2-mm wire sieve. Crop residues that do not pass through the 2 mm sieve were weighed and kept for future carbon analyses. Any stone material greater than 2 mm was weighed and subtracted from the gross weight and then discarded. From the top one (in 2000) or two depths (in 2004), 500 grams of fresh soil material were collected and placed in a plastic bag and stored in a 0$^0$C cooler for later MBC analysis (within two months). The remaining soil material from each depth was air dried and placed in a plastic bag to be sub-sampled from for SOC analysis or archived.

Soil samples were analysed for fertility and SOC using procedures in Methods Manual Scientific Support Section Analytical Chemistry Laboratory (1998). In 2000 MBC was determined using the chloroform fumigation-extraction procedure described by Voroney et al. (1993) for the top (0-15 cm) soil depth at all site locations within each pasture for every pasture. In 2004, MBC was again determined, however microbial biomass nitrogen (MBN) and soil microbial dehydrogenase (SMD) were also added to the microbial parameters measured. Microbial biomass nitrogen was determined using the Voroney et al. (1993) procedure and SMD was determined using the procedure of Tabatabai (1982). All the microbial parameters in 2004 were measured at two depths (0-7.5 and 7.5-15 cm). The soil microbial biomass acts as the transformation agent of the organic matter as it is both a source and sink of several soil nutrients. It is defined as the living portion of the soil OM, excluding the plant roots and soil animals larger than $5 \times 10^{-3}$ µm. Microbial biomass nitrogen is useful to assess the soil N fertility status and specifically the amount of N in the microbial biomass. The SMD is an enyzme found only within living microbial biomass and is an indicator of overall oxidative metabolic activity.

*Soil fertility*

Soil samples were taken from each of the 16 pastures at the end of April for all years to evaluate soil fertility characteristics (i.e., N, P, S and K levels). Four random sites within each pasture at three depths (0-15, 15-30 and 30-60 cm) were sampled and chemical analyses were determined using the Methods Manual Scientific Support Section Analytical Chemistry Laboratory (1998).

***Year 2001 small plot studies***

*Seral stages*

The objective of this study was to examine the effects of seeding native species in a manner that more closely mimic natural plant community development. Seed mixes included early seral and late seral species, as well as the simple and complex seed mixes that were used in the large pasture study. In addition to comparing mixes (i.e., simple and complex and seral development) the study will also evaluate the time and order each seral mixture was seeded and during what season (summer and fall) (Appendix 2). Seeding rates for the simple and complex mixtures were 100 pure live seeds (PLS) per m and for the seral mixes 50 PLS per m.

The fall seeding treatment for site one was carried out in late November of 2001 using a six-row disc drill with 30 cm row spacings. All species were seeded at a 12.5 mm (0.5 in) depth except for the shrubs and forbs provided by Grasslands National Park (Canadian Heritage Parks Canada) which were seeded at 6.2 mm (0.25 in) depth.

### *Optimum Date of Seeding Study*

The seed mixtures for this study were the same as the previous two mixes (simple and complex) used in the large pasture study. Seeding rate was 100 pure live seeds per m for both the simple and complex mixtures. The various seeding treatments for the study can be found on Appendix 2. Seeding dates included two fall dates, one in September within one to two days of 12.5 mm of rainfall and the second in October after the soil temperature drops below 5 degrees C. The spring dates are planned to occur in 2002 in late April, late May, and late June all to be carried out within one to two days of a 12.5 mm rainfall with the fourth spring seeding date being June 21.

Due to the absence of rain in the fall of 2001 we were unable to carry out the September seeding treatment and had to seed this in fall of 2002. Due to unseasonably warm temperatures during the fall the October seeding treatment was postponed to November when the temperature dropped sufficiently for us to seed. This was seeded on November 7 at a 12.5 mm (0.5 in) depth using the six-row disc drill with 30 cm row spacings.

### ***Year 2002 small plot studies***

### *Seral stages* (S2)

For data collection year 2002 the dormant fall seeding occurred 23 and 26 November 2001. The spring seeding date occurred 29 and 30 May 2002. Plots were split into thirds and one third was randomly selected for hand weeding. Weeding commenced 26 June and was completed 24 July 2002.

Plant counts were done for a 0.45 $m^2$ area 14 to 22 August 2002. Light readings were done 23 August 2002 using a LI-Cor quantum meter model LI-250. Fall species compositions for a ¼ $m^2$ with canopy diameters were done 9 to 23 September 2002. Plots were harvested using a flail mott 18 September 2002. Soil moistures were obtained 17 May, 29 May, 21 June, 18 July, 19 August, 24 September and 8 November.

Site 2 of this study was started in the fall of 2002. The fall seeding was carried out in early November with the grasses seeded at (0.5 in) and the forbs and legume seeded at (0.25 in) as in Site 1. As the ground was too frozen to take TDR readings at the time of seeding, soil samples were taken from each rep and gravimetrics were analyzed in the lab.

*Optimum Date of Seeding Study (S1)*

For data collection year 2002, the first fall seeding date took place at the end of September 2001 but the fall dormant seeding date took place on 9 November 2001 after the soil temperature had decreased to below 5 $^0$C rather than the proposed date of October. The first spring seeding date was done 9 May 2002 lack of rain prevented seeding following 12.5 mm rainfall event. The second spring date of 28 May 2002 was on schedule. The third seeding date occurred 26 June 2002. The last date of seeding was done on 8 July 2002.

The wet conditions of 2002 resulted in ideal conditions for weed growth. The plots were split into thirds with a third being randomly selected for hand weeding. This was done to examine impact of weeds on resulting species mixes. A number of organizations providing financial support are interested in no weed control management. Weeding occurred during the period of 12 to 24 July 2002.

Plant counts were done for a 0.45 $m^2$ area from the 25 July to 2 August 2002. Light readings were done 23 August 2002 using a LI-Cor quantum meter model LI-250. Fall species compositions for a ¼ $m^2$ with canopy diameters were done 10 to 23 September 2002. Plots were harvested using a flail mott 19 September 2002. Soil moistures were obtained 9 Nov 2001, 9 May 2002, 17 May, 28 May, 21 June, 24 June, 8 July, 18 July, 19 August, 24 September and 7 October.

The 2nd site was started in the fall of 2002. F1 seeding treatment was seeded on October 4/02 and TDR readings taken. F2 treatment was seeded on October 24/02. The ground was too frozen to use TDR readings therefore gravimetrics were utilized for % moisture. On 6 and 7 November 2002 fall seeding for the second site occurred.

***Year 2003 small plot studies***

*S2 - Seral stages study (01614 & 02622)*

For data collection year 2003 the dormant fall seeding for site 2 occurred 6 to7 November 2002, site 1 seeding occurred 23 and 26 November 2002. Spring seeding occurred 29-30 May for site 1 and 21 May for site 2. Fall seeding to have occurred in 2003 was not done due to snow cover and will be done at the earliest possible date in spring 2004.

Plots were split into thirds and one third was randomly selected for hand weeding. Weeding occurred the latter part of July.

Light readings were done 29 August for site 1 and 2 September for site 2 at high noon, on a clear day, using a LI-Cor quantum meter model LI-250. Fall species compositions for a ¼ $m^2$ with canopy diameters were done 30 September until 15 October. Plots were harvested at the same time as the plant compositions were determined. Soil moistures were obtained 26 May, 26 June, 28 July, 26 September for site 1 and 26 June, 28 July, 29 September for site 2.

*S1 - Optimum seeding date study (01615 & 02623)*

For data collection year 2003, the first fall seeding date for the second site took place 4 October 2002 and the second 24 October 2002 after the soil temperature had decreased to below 5C. The first spring seeding date was done 29 April 2003, second date was 27 May, third was 20 June and the fourth 25 June.

The initial wet conditions of 2003 resulted in ideal conditions for weed growth. The plots were split into thirds with a third being randomly selected for hand weeding. This was done to examine impact of weeds on resulting species mixes, no weed control being of interest to a number of organization providing financial support. Weeding occurred during the latter part of July.

Light readings were done 25 August using a LI-Cor quantum meter model LI-250 at high noon, on a clear day for both sites. Fall species compositions for a ¼ $m^2$ were done 2 to 19 September for both sites. Plots were harvested at this same time as plant compositions were taken for the second site but due to snowfall and excessive time required for plant compositions site 1 was not harvested. Soil moistures were obtained 26 May, 26 June, and 29 September for site 1 while site 2 soil moistures where obtained 26 June and 26 September.

### *Year 2004 small plot studies*

#### *S1 - Optimum seeding date (01615 & 02623)*

Weeding of plots was stopped to insure completion of data collection. Also, the weed component was minor by the second year. Soil moisture was determined by time domain reflectometry monthly starting 7 May ending on 6 August. Light readings were done from 11:30 AM to 1:30 PM Central Time on 27 and 31 August, when the sun was at its zenith. Plant composition was determined for the site 1, seeded fall 2001 and spring 2002, 8 September to 17 September and 30 September to 5 October for site 2, seeded fall 2002 and spring of 2003. Dry matter was harvested at the same time as when the plant compositions were determined.

#### *S2 - Seral stages study (01614 & 02622)*

Weeding of plots was stopped to insure completion of data collection. Also, the weed component was minor by the second year. Soil moisture was determined by time domain reflectometry monthly starting 7 May ending on 6 August. Light readings were done from 11:30 AM to 1:30 PM Central Time on 27 and 31 August, when the sun was at its zenith. Plant composition was determined for the site 1,started in 2001, 23 - 19 September and 5 - 26 October for site 2, started in 2002. Dry matter was harvested at the same time as when the plant compositions were determined.

### *Statistical Analyses*

All data for the large pasture (e.g., forage production, forage chemical constituents, SOC, microbial characterization etc.) and animal performances (e.g., ADG, TLP etc.) were analyzed using the MIXED procedure from the SAS Institute, Inc. (2000). Model used for the forage and animal dependent variables (yield, chemical constituents, ADG, TLP etc.) included the effects of seed mixtures (simple or complex), pasture utilizations (50 or 70%), year and their interactions. Another analysis was done for forage quality in which the model included the effects of seed mixtures, utilization, season (spring, summer and fall), year and their interactions. Since year was a repeated measure, various variance-covariance structures were fitted and the best model was selected for the final analyses. The model used for the SOC dependent variable included the effects of seed mixtures, pasture utilizations and their interactions. Treatment means were compared using single degree of freedom orthogonal contrasts. Contrasts tested included: (1) complex-high vs. complex-low, (2) complex-high vs. simple-high, (3) complex-high vs. simple-low, (4) complex-low vs. simple-high, (5) complex-low vs. simple-low, and (6) simple-high vs. simple-low. Differences were considered to be significant when $P < 0.05$. The model used for the microbial dependent variables (MBC, MBN and SMD) included the effects of seed mixture + pasture utilization (none, low or high). Fisher's protected LSD test (Steel and Torrie 1980) was used to evaluate differences among means for significance. The differences were considered significant if $P < 0.05$.

All the data for the small plot studies were analyzed using the General Linear Model Procedure (SAS Institute, Inc. 2000) and significance level was set at $P<0.05$. A Tukey's test (Steel and Torrie 1980) was used for mean separation when factors were found significant.

## Results and Discussions

### *Native establishment*

*Assessment of seeding success*

The year, 2002, might be considered a year of contrasts. The drought of 2001 and the very cool and dry spring of 2002 renewed concerns of another drought forecast, however, by mid summer abundant moisture was received far above normal long term averages (Appendix 1). Based on the results from the density or plant count measurements, a successful stand establishment (four to five plants per 0.30 $m^2$) (Wark et al. 1985) was achieved in 12 out of the 16 pastures. The remaining four pastures had plant counts greater than three plants per 0.30 $m^2$, which was considered quite acceptable but requires reevaluation the following year. Plant counts among the 16 pastures ranged from 3.1 to 7.4 plants per 0.30 $m^2$ (overall avg. = 5.2 plants per 0.30 $m^2$). Results from this study showed that a Bourgault disk air seeder was successful in seeding a diverse mixture of native grass species into standing stubble, however, careful monitoring of the seeding is needed to ensure a uniform flow of seed and prevent seed bridging problems which can result in skips and seeding misses. This may have occurred in pasture seven in which a portion of the pasture was not seeded while the other half had good successful stand establishment. Successful native stand establishment was also facilitated by good pre and post weed control. Of the fourteen grass, forb and shrub species seeded, only two [June grass (JG) and saltbush] were not observed in the pastures (Fig. 1). Wheatgrasses, green needle grass (GNG), needle and thread grass (NTG), blue grama (BG), little bluestem (LBS) and purple prairie clover (PPC) were commonly observed. In contrast to previous research conducted at AAFC-SPARC, successful establishment of warm season grasses was not a problem.

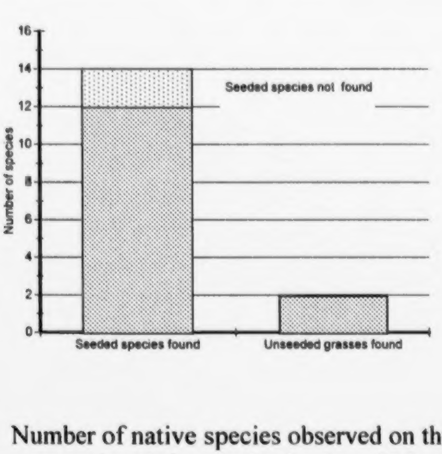

**Figure 1.** Number of native species observed on the newly established pastures (seeded at the beginning of May of 2001).

The absent of JG seedlings in the pastures were possibly due to its low pure live seed (PLS) percentage (65%). However both GNG (59%) and LBS (44%) had lower PLS values and yet were commonly observed throughout the large pastures. June grass produces high volume of seed but the seed can have low viability (Looman 1978) and germination (Tannas personal communication 2003). The observed poor germination of saltbush may also be due to its low PLS value (46%) and seed dormancy. A small amount of two native grass species (big bluestem and side-oat grama), not included in the native seed mixtures, was observed in one pasture and was most like due to seed contamination.

### *Species composition for the large pastures*

As expected the wheatgrasses (i.e., WWG, NWG, SWG and AWG) were the predominant species observed for the simple and complex seed mixtures (Table 1). Many of the wheatgrass species used in the two seed mixtures for this study have good germination and establishment rates and therefore, were highly competitive (Hammermeister and Naeth 1999). As stated earlier, all other grasses were observed, except for JG. Surprisingly, PPC, BG and LBS were observed throughout all the pastures and for the different seed mixtures. Purple prairie clover constituted about 1% of the simple mixture and was about 2% for the complex mixture. However, its observed occurrence in the simple mix was much lower than for the complex mixture, and this may have been a result of the increased competition from the wheatgrass species that predominate the simple mixture. In 2002, the spreading ability of WWG was already easily observed, as well as, several other rhizomatous and tillering grass species, therefore, the amount of bare ground present in the pastures should decline. The first year in which grazing was conducted was in 2002 and data collected over the next two years will be used to evaluate whether grazing can affect species composition of the pastures.

**Table 1.** 2002 mean native establishment species composition based on percent canopy cover.[1]

| Seedmix | Wheat grasses | Other grasses | Purple prairie clover | Warm season grasses | Weeds & trash | Bare ground |
|---|---|---|---|---|---|---|
| *Simple* | 33.5 | 0.19 | 0.01 | -------- | 26.24 | 40.06 |
| *Complex* | 25.7 | 1.35 | 0.1 | 4.34 | 29.94 | 38.58 |

[1] Wheatgrasses = western, northern, slender and awned; other grasses = green needle grass, needle and thread grass, prairie sandreed or Canada wildrye; warm season grasses = blue grama and little bluestem.

## ***Estimation of soil carbon associated with the native establishment study***

### *Total soil organic carbon*

A major potential sink for sequestering C is in agricultural soils. It is estimated that soil that has never been ploughed is at equilibrium and not sequestering or emitting C (Bruce et al.1999). However, soil will sequester C after it has lost its soil C from cropping; soil that is being annually ploughed is a source of C into the atmosphere. Cropped land can lose most of its SOC within the first few years of cropping. Gebhart et al. (1994) observed losses of 24 to 60% SOC due to long term cultivation. The estimates of C lost from newly cultivated soils are based on the assumption that 20% of the soil C is lost in the first five years following disturbance of natural vegetation and another 5% is lost before a new steady state equilibrium is reached 20 years after tillage started (Houghton et al. 1991). When cropped land is converted to permanent cover, the soils begin to sequester C at a higher rate than cropped land and become a sink. Since C levels continue to slowly decline with cultivation, how long land has been cultivated will influence the rate of sequestration after seeding to permanent cover. Carbon levels will increase rapidly after permanent establishment, and then slow as C continues to approach the equilibrium levels found in native soil.

Results from this study found that the average SOC level for the land (16 pastures) in 2000 prior to the seeding of the native pastures was about 28 Mg C ha$^{-1}$ and this is what would be expected for land that had been in a crop-fallow rotation system for more than 80 years (Campbell et al. 2005) (Fig. 2). Figure 2 shows the average total amount of C that was sequestered (2.12 Mg C ha$^{-1}$) by the two native perennial pasture mixtures over the four years and the potential C level existing in an undisturbed native mix grassland. The average C sequestration rate annually on the newly established native mixed grass land was 530 kg ha$^{-1}$ yr$^{-1}$. Bruce et al. (1999) and Schuman et al. (2002) report that 100 to 800 kg ha$^{-1}$ yr$^{-1}$ of soil C can be sequestered when converting crop land into grasslands (tame and native forage species) and that the first 10 years of perennial grass establishment after seeding will have the highest sequestration rates (Bruce et al. 1999; Follett et al. 2000). However, these rates of accrual will diminish with time, particularly because a large part of the initial C gain may occur as roots and other plant litter. In addition, rates of C sequestration will vary depending on climate and soil conditions. For example, mesic environments with high productivity show greater rates of accumulation (Jastrow 1996) than less productive semiarid grassland (Dormaar and Smoliak 1985; Burke et al. 1995). Mensah et al. (2003) reported net gains of 600 to 800 kg C ha$^{-1}$ yr$^{-1}$ on seeded grasslands into cultivated land in east central Saskatchewan after five to twelve years of establishment. This study was seeded to a mixture of wheatgrasses, blue grama and alfalfa on dark Brown and thin Black soils that had been cropped for 80 years. In comparison, the amount

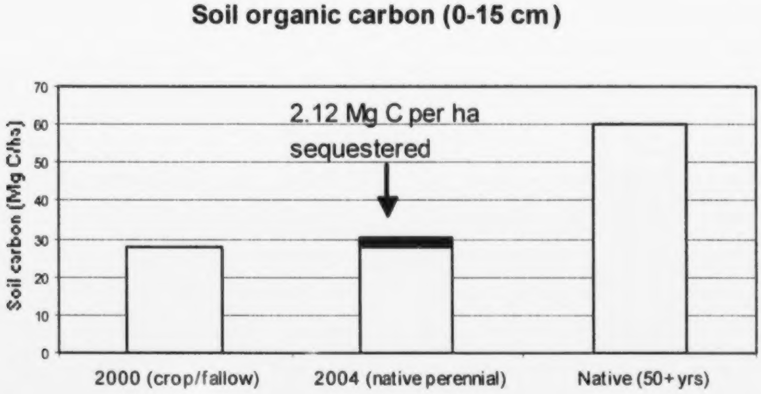

**Figure 2.** Total soil organic carbon comparison (first bar shows the current SOC level as of 2000 and the other bars represent actual and potential C sequestration and equilibrium).

of C sequestered from our two native seeded pastures (mostly wheat grasses, some other cool and warm season grasses and one native legume) compared very favourably to the results reported by Mensah et al. (2003) on dark Brown and Black soils which should have much higher SOC productivity. It is important to remember that favourable moisture conditions and good forage productivity generally occurred during our research study, which greatly contributed to the excellent C sequestration potential.

Study results observed a significant seed mixture x pasture utilization ($P < 0.05$) interaction. Contrast statements were used to separate out the seed mixtures by pasture utilization effects on SOC. The simple + high (S+H) treatment gave the highest ($P < 0.05$) SOC level compared to the other three treatments: complex + low (C+L), simple + low (S+L) and complex + high (C+H) (Table 2). Higher SOC associated with the S+H versus S+L treatments may be due to the higher animal pasture utilization (70% vs 50%) which resulted in more livestock hoof action breaking down and incorporating the standing dead and litter into the soil and enhancing decomposition and reducing loss through oxidation (Schuman et al. 1999). Schuman et al. (1999) using light (0.23 steers $ha^{-1}$) and heavy (0.56 steers $ha^{-1}$) stocking rates were able to determine a difference in soil C from grazed versus ungrazed treatments but not between the two difference stocking rates. The stocking rate in this study for the 70% pasture utilization was 4.0 steers $ha^{-1}$ and the 50% pasture utilization was 2.0 steers $ha^{-1}$, therefore the higher stocking rates may explain why a higher SOC effect was observed for the S+H treatment in this study. In addition, the simple seed mixture generally had the highest available forage production (Table 3), especially during the first year of establishment compared to the complex seed mixture. Since the major factor driving SOC accumulation is productivity (above and below ground) it is not surprising that a simple seed mixture treatment would have the highest SOC value. In support, the only significant main effect that was observed was for seed mixture (Table 2). Higher ($P = 0.04$) mean SOC values for the simple compared to the complex native seed mixture were found and the values were 2.53 and 1.48 ± 0.83 Mg C $ha^{-1}$, respectively. Higher ($P < 0.05$) SOC were also observed for S+H versus C+H treatments. This may be due to the less SOC potential of the complex seed mixture due to generally lower available forage production over the three years or a combination of both lower forage production and higher stocking rate may have resulted in stressing the pasture

**Table 2.** Least square means for soil organic carbon levels (Mg C $ha^{-1}$) for simple and complex seed mixtures that have been grazed to two different pasture utilization levels (low or high) over four production seasons (2002 to 2005) on the native establishment study.

| | Pasture utilizations | | |
|---|---|---|---|
| Seed mixtures | High | Low | Overall |
| Complex | 0.94d (0.68)[1] | 2.03 | 1.48 (0.83) |
| Simple | 3.59be | 1.47a | 2.53 |
| Overall | 2.27 (0.83) | 1.75 | |

[1] Standard error

a-b Lsmeans in the same row with different letters differ ($P < 0.05$).

d-e Lsmeans in the same column with different letters differ ($P < 0.05$).

species and reducing below ground production. Although not significant, a higher numeric SOC value was observed for the C+L versus C+H and this may be a result of higher number of native specie establishing under less grazing pressure and thus providing a more diverse root mass system and potentially sequestering C at several different levels in the soil profile (Frank et al. 1995; Schuman et al. 1990). A higher numeric SOC value was also observed for C+L versus S+L treatment. However, Whitman et al. (1943) concluded that greater than 60 years might be needed to develop climax vegetation by natural re-vegetation of abandoned fields in southern Alberta. Therefore it may be not surprising to find a lack of significant difference in SOC between the other treatments (e.g., high vs. low pasture utilizations, Table 2), especially due to the short period of time the AAFC-SPARC grazing study has been running (2002 to 2004). Potter et al. (2001) studying the effect of different stocking rates on SOC found that grazing effect may be more dependent on site factors such as soil texture. Thus longer research is needed before definite conclusions can be made on the effects of seed mixtures and pasture utilization or stocking rates.

Within each of the 16 pastures a pasture enclosure (3.6 x 3.6 m) was used for the ungrazed treatment. The mean SOC measurements (0 to 15 cm) over the four years of the study did not differ ($P = 0.62$) between grazed and ungrazed treatments and the values were 1.90 and 2.62 ± 1.43 Mg C ha$^{-1}$, respectively. These results are in contrast to a number of other research studies that have reported a benefit to grazing and higher grazing pressure on increasing soil C (Smoliak et al. 1972; Dormaar and Willms 1990; Manley et al. 1995; Schuman et al. 1999). However, difference in environmental conditions, plant community and duration and intensity of the grazing treatment may be possible reason for contrasting results. Other researchers (Milchunas and Lauenroth 1993; LeCain et al 2000; Henderson et al. 2004; Bai et al. 2005) have also found no clear relationship between species composition, root biomass, SOC, soil nitrogen on grazed versus ungrazed grasslands. Although results from this study did observed more specie diversity associated with grazed versus ungrazed pastures and some shifting of the specie composition due to higher pasture grazing utilizations (refer to Large Pasture Plant Composition) the overall conclusion is that plant communities are still evolving under different grazing and utilization treatments. Thus, it is too soon yet to determine potential SOC differences between grazing and pasture utilization treatments, especially when all of the grazing studies cite previously were 10 to 25 years in length.

Native grasses have more extensive rooting system than tame species since natives have had to evolve in a climate where droughts are frequent (Coupland 1992). In this study the mean annual C sequestration rates for the simple and complex pasture mixtures were 634 kg C ha$^{-1}$ yr$^{-1}$ and 371 kg C ha$^{-1}$ yr$^{-1}$, respectively. These C sequestration values compare similarly or higher to some tame forages (pubescent wheatgrass, etc.) C sequestration ranges (256 to 500 kg C ha$^{-1}$ yr$^{-1}$) that have been established (six to 10 yr durations) on Brown or Dark Brown soil land's in Canada that were annually cultivated (Smith et al. 2001; Bremer et al. 2002). McConnell and Quinn (1988) reported that native range and abandoned (re-established native) fields had more surface SOC than reseeded tame forages. In support, other researchers (Smoliak and Dormaar 1985; Wedin and Tilman 1996; Whalen et al. 2003) have reported that total C is significantly lower in soils under modified plant communities [crested wheatgrass (CWG), Russian wildrye etc.] than on native range. Christian and Wilson (1999) calculated CWG actually sequestered 25% less than natives. In contrast, Willms et al. (2005) reported greater mass of SOC in CWG and RWR than in certain tufted native species. However the study suggested that the relatively short period of time that has occurred in the study may be insufficient for certain treatments (e.g., native) to achieve their potential expression. The introduction of a nitrogen-fixing legume (e.g., alfalfa) may result in an increase in SOC initially, although C sequestration rates will decline with time (Mortenson et al. 2002). Legumes are expected to yield a higher rate of C sequestration compared to cool season grasses and mean sequestration range for legume and legume+grass mixtures have been around 750 to 900 kg C ha$^{-1}$ yr$^{-1}$, four to 10 years after seeding (Conant et al. 2001; Wu et al. 2003). In this study, over the three production year it has been observed that PPC, BG and LBS were increasing, thus higher C sequestration levels may be observed in the future soil sampling period in 2008.

*Microbial biomass carbon, nitrogen and dehydrogenase activity*

Mean MBC level was 357 mg C kg$^{-1}$, which was expected. Normal range for MBC on similar crop-fallow rotation system would be 300 to 500 mg C ha$^{-1}$. Mean MBC did not differ (P = 0.11) among seed mixtures (simple or complex) and pasture utilization levels (no grazing, low stocking or high stocking) (Fig. 3). The MBC values ranged from 200 to 436 ± 93 mg C kg$^{-1}$ among treatments with the simple no grazing treatment containing the highest MBC. This was not surprising since the simple mixture had the highest available forage production and C sequestration level. While the land was in perennial forage cover (2001-2004) the MBC content increased between 60 to 100% among the different treatments. Study results show evidence that the resident soil microbial population under a previous annual cropping system (80+ yrs) can continue to subsist and adapt and expand in a perennial native forage system quickly. At this stage MBC content did not differ between the two native mixtures and this may be a result that the plant communities are still evolving. Hammermeister and Naeth (1999) concluded that the rapid establishment of the wheatgrasses may prolong and competitively repress the normal plant community session. The rapid establishment of the wheatgrasses (e.g., SWG, NWG and WWG etc.) found in both native seed mixtures may have contributed to the similar MBC contents among treatments. Although the highest MBC content was associated with the simple native mixture under no grazing, in time this may result in a decline in MBC and C sequestration

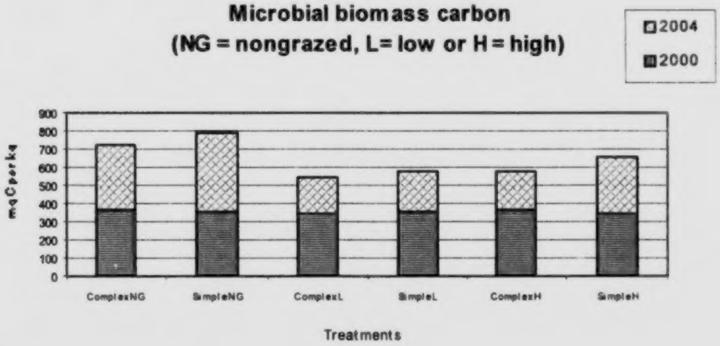

**Figure 3.** Mean microbial biomass carbon over three production years on different native mixtures (simple or complex) and under different grazing utilization (none, low or high).

potential. Study results have reported that plant community in the ungrazed enclosures are less diverse than grazed pastures ( refer to Large Pasture Plant Composition). Higher species richness is associated with grazed pastures and this could result in higher C sequestration and MBC levels in the future (Schuman et al. 1990; Wedin and Tilman 1996).

Difference ($P < 0.01$) in MBN among seed mixtures and pasture utilizations were observed (Fig. 4). Explanations for the observed results were similar to those given for MBC. Higher biomass productions from the ungrazed simple and complex native mixtures resulted in greater plant litter compared to the grazed treatments and thus more microbial activity. The range of MBN values observed were 56 to 99 ± 11 mg N kg$^{-1}$ of soil.

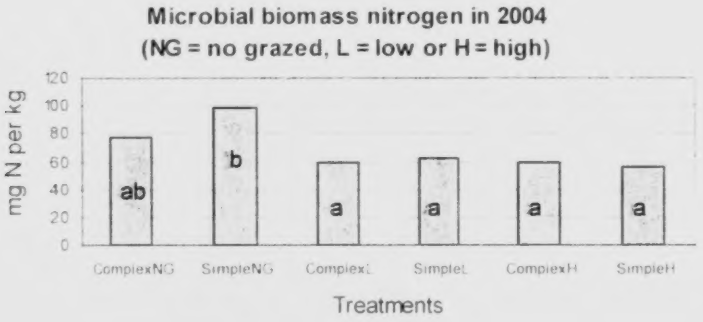

**Figure 4.** Mean microbial biomass nitrogen levels for different native mixtures (simple or complex) and grazing utilizations (none, low or high) (different letter are different $P < 0.05$).

The dehydrogenase activity did not differ ($P = 0.21$) among seed mixtures and pasture utilizations treatments (Fig. 5). As expected the highest dehydrogenase activity was associated

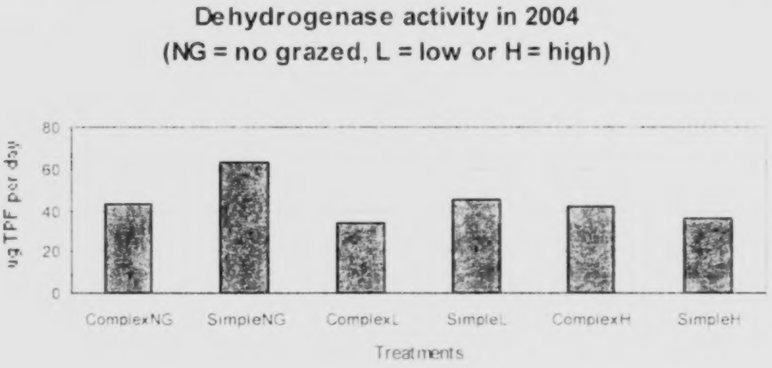

**Figure 5.** Mean dehydrogenase activities for different native mixtures (simple or complex) and grazing utilizations (none, low or high) on the native establishment study.

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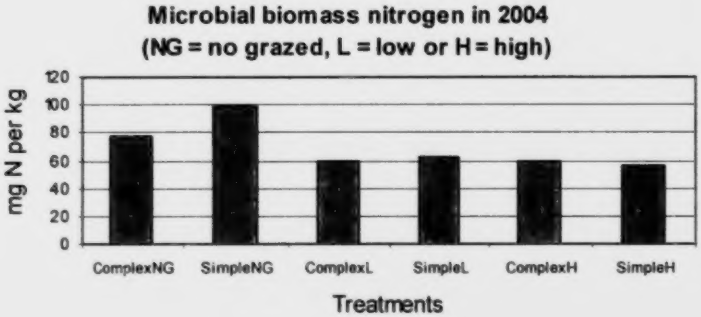

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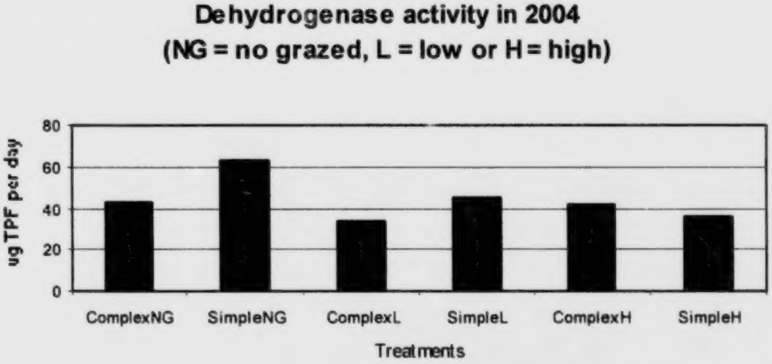

**Figure 5.** Mean dehydrogenase activities for different native mixtures (simple or complex) and grazing utilizations (none, low or high) on the native establishment study.

with simple ungrazed treatment. The range of microbial dehydrogenase activities observed were 33 to 63 ± 11 mg TPF produced per day.

*Available C associated with litter for the native establishment study*

After four years the total amount of C associated with the litter for the simple and complex native mixtures under grazing were 352 and 313 ± 97.9 kg C $ha^{-1}$, respectively. The amount of C associated with the litter for the high and low pasture utilizations were 307 and 359 ± 97.4 kg C $ha^{-1}$, respectively. As expected the amount of litter for a simple native mix, under low pasture utilization were higher. Under an ungrazed situation the amount of C associated with the litter for the simple and complex native mixtures were 613 and 451 ± 61.6 kg C $ha^{-1}$, respectively. Coupland et al. (1975) reported that on an undisturbed grassland in Saskatchewan about 2,000 kg litter C $ha^{-1}$ $yr^{-1}$ is produced and of which 50% enters to soil. Van Veen and Paul (1981) reported about 800 kg C $ha^{-1}$ enters into the top 0-15 cm and the remaining 200 kg C $ha^{-1}$ resides in the 15-40 cm soil layer. Litter accumulation and its eventual entrance it the soil is an important process of C sequestration. The quantity and properties (e.g., cool vs. warm seasons, C/N ratio of the plant etc.) of the plant materials entering the soil are important and can influence C sequestration rates (Follett 2001), therefore, further evaluation of SOC of the native pastures is needed in the future.

**Forage production and quality and grazing performance on different native pastures**

*Available forage production*

No significant (P = 0.89) three-way interaction occurred for available forage production over the four years. However, significant two-way interactions occurred for seed mixture x year (P = < 0.01) and seed mixture x pasture utilization (P < 0.05). Results from the seed mixture x year interaction found a higher (P < 0.01) available forage production for the simple versus the complex native mixture in 2002 (Table 3). Higher forage production for the simple versus the complex seed mixture in 2002 was expected since the wheatgrass species made up a higher proportion of the simple (i.e., 61%) compared to the complex seed mix (30%). The wheatgrasses

**Table 3.** Least square means for available forage production (kg $ha^{-1}$ DM) for simple and complex seed mixtures harvested at the start of the grazing season over four production seasons (2002 to 2005) on the native establishment study.

| | Year | | | | |
|---|---|---|---|---|---|
| Seed mixtures | 2002 | 2003 | 2004 | 2005 | SE[1] |
| Simple | 2,510ce | 1,274b | 960a | 1,009a | 125 |
| Complex | 1,532bd | 1,285b | 932a | 907a | 125 |
| SE[1] | 253 | 133 | 74 | 84 | |

[1] Standard error

a-c Lsmeans in the same row with different letters differ (P < 0.05).

d-e Lsmeans in the same column with different letters differ (P < 0.05).

contained in the simple mix were cool season, aggressive and high producing, with most of their above ground production occurring in July, while the complex seed mix consisted of a warm season legume (i.e., PPC) and several grasses (i.e., BG and LBS) that have their forage production occurring in late summer and early fall. However, available forage productions between the two native mixtures over the four years did not differ ($P > 0.05$) after 2003. These results were surprising since it was expected that the simple native mixture containing more wheatgrass species would dominate the forage production for more than one year. Clearly, the excellent forage yields obtained by the simple mix in 2002 was not sustainable and the yields dropped significantly in 2003. This reduction in available forage production at the start of the grazing season in 2003 may be a result of the grazing effect that occurred in 2002 and/or the reduction in forage potential of some cool season grasses after one production year. The release of organic nitrogen after seeding and the high rain fall received in 2002 may have provided the necessary conditions to produce very good forage production but this was not sustained and production declined in 2003. Definitely the excellent moisture received in 2002 (Appendix 1) contributed to the successful establishment and forage production of a number of other grass species (GNG, NTG, LBS, BG and PPC) that were part of the complex native seed mix and this could have reduced the forage production differences between the two native seed mixes. Other factors that may have contributed to the initial high forage production observed for the simple mix were the presence of high producing but short lived grass species such as SWG and AWG which contributed about 18% of the simple mix compared to only 6% of the complex mix. By 2004 under grazing the SWG and AWG were declining and this may also explain why the forage productions from the two native mixtures were becoming similar (refer to Large pasture plant composition). Comparing forage productions over the four years for the two native mixtures showed that the highest available forage yields occurred in the first two years of production and by the 3rd and 4th production years the available forage yields were similar and had reached a steady forage production state (Table 3).

Study results observed higher ($P < 0.05$) available forage yields with the simple seed mix under low compared to high pasture utilization. These results could be expected simply from the differences in grazing pressure, low vs. high. Shifts in individual plant species due to grazing may provide another explanation for the forage yields differences over the four years of production (Table 4). Schellenberg, in this report suggested that SWG may be more sensitive to grazing, and that this specie, as well as others, were declining under grazing. In agreement, (Alberta Agriculture 1981; Hardy BBT Limited 1989) reported that SWG has low resistance to close and/or heavy grazing and declines quickly under competition with other wheatgrasses. The ability of the complex native mix to have forage yields that did not differ ( $P > 0.05$) between the two pasture utilizations could be a result of the increase biodiversity existing in the complex pasture (i.e., cool and warm season grasses) and thus providing more flexibility in the plant community to adapt to the grazing treatments (Tilman et al. 2001). Higher ($P < 0.05$) available forage production for the simple versus the complex native seed mix under a low pasture utilization was not surprising since the simple mix contained more aggressive and higher producing wheatgrasses while the complex mix contained other grasses not as productive in the spring (e.g., warm season grasses) (Table 4). As discussed above, the lack of difference ($P > 0.05$) between the two native mixtures under a high pasture utilization may be a result of the decline of certain grass species in the simple mix and the higher biodiversity of the complex mix for that period of time. It is quite plausible to expect further shifting and evolving of the plant communities under grazing, especially at a high pasture utilization (60 to 75%), since many decreaser grass species (WWG, NTG etc.) will decline under heavy grazing (Alberta Agriculture 1981; Smoliak et al. 1982). Further evaluation of the newly established native pasture mixtures is needed to determine how soon the effects of heavy grazing may become non-beneficial.

**Table 4.** Least square means for available forage production (kg $ha^{-1}$ DM) for simple and complex seed mixtures that have been grazed to two different pasture utilization levels (low or high) over four production seasons (2002 to 2005) on the native establishment study.

| | Pasture utilizations | | |
|---|---|---|---|
| Seed mixtures | High | Low | SE[1] |
| Complex | 1209 | 1,078d | 144 |
| Simple | 1,264a | 1,613be | 144 |
| SE[1] | 144 | 144 | |

[1] Standard error

a-b Lsmeans in the same row with different letters differ ($P < 0.05$).

d-e Lsmeans in the same column with different letters differ ($P < 0.05$).

*Forage quality measurements of the available forage production*

No significant interactions were observed for any of the major forage quality measurements (%OMD, %NDF, %CP etc.), therefore, only main effects will be reported. All forage quality measurements were significant ($P < 0.0001$) for year effects (Table 5). In 2002, %OMD was lower ($P < 0.05$) than in 2003 and 2004 (Table 5). The lower %OMD was due to higher ($P < 0.05$) %ADF and %NDF values for 2002 versus the other two years. An explanation for the

**Table 5.** Least square means forage qualities of the available forage production for the three production years (2002 to 2004) on the native establishment study.

| | Year | | | |
|---|---|---|---|---|
| Items | 2002 | 2003 | 2004 | SE[1] |
| OMD[1] (%) | 50.62a | 55.08b | 55.27b | 0.46 |
| ADF[1] (%) | 36.75b | 33.08a | 33.60a | 0.55 |
| NDF[1] (%) | 62.93c | 59.88a | 60.96b | 0.48 |
| CP[1] (%) | 7.68c | 6.43a | 7.15b | 0.18 |
| Phosphorus (%) | 0.21b | 0.18a | 0.18a | 0.006 |

a-c Lsmeans in the same row with different letters are significantly different ($P < 0.05$).

[1]SE = standard error, OMD = organic matter digestibility, ADF = acid detergent fibre and NDF = neutral detergent fibre and CP = crude protein.

poorer forage quality observed in 2002 was due to the lack of much spring growth by the cool season grasses (drought like conditions) followed by a very wet and cloudy conditions. Reduction in sunlight as an energy source can result in higher cell wall concentrations in the plant and thus lower digestibility (Van Soest 1982). In addition, the native pasture in 2002 would have responded to the organic nitrogen that was made available from the seeding disturbance in 2001. This improved fertility being utilized by aggressive and productive grasses would have resulted in a plant growth with decrease digestibility and soluble carbohydrate contents while %CP content would increase (Van Soest 1982), which is what was observed in 2002. The CP value was higher ($P < 0.05$) in 2002 versus 2003 and 2004 (Table 5). Higher ($P < 0.05$) %P level in 2002 compared to 2003 and 2004 could also be expected from the rapid growth and cell wall and CP accumulation occurring.

Higher ($P < 0.05$) %NDF value was observed for the complex versus the simple seed mixture and the values were 61.74 and 60.77 ± 0.39%, respectively. All other forage qualities measurements did not differ ($P = 0.17$) between native seed mixtures. Higher %NDF for the complex compared to the simple native mixture was expected since the complex native mixture contains a number of warm season grass species which would have higher cell wall contents (Cherney and Allen 1995).

Comparing the forage qualities of the two native pastures for the three grazing seasons (spring, summer and fall) over the three production years found no significant ($P = 0.45$) three way interactions (seed mixture x season x year), however, significant ($P < 0.05$) two way interactions (season x year, seed mixture x year and seed mixture x season) occurred for certain dependent variables (%OMD, %ADF, %NDF and %CP). As previously reported, changing environmental conditions throughout the three production years (2002 to 2004) significantly affected the forage qualities of the native mixtures as the grazing season progressed and is an explanation for the significant season x year and seed mixture x year interactions. The significant ($P < 0.05$) seed mixture x year interaction for percent OMD, ADF, NDF and CP found that the complex had better nutritional values over the simple native mix (Figs. 6, 7, 8 and 9). Consistently the complex native mix had a higher %OMD and %CP over the simple native mix over the entire grazing season. As the grazing season progressed the simple mix cell wall components (%NDF and %ADF) increased until they were higher in the fall compared to the complex native mix. Although animal grazing ADGs in the fall (simple mix = 0.24 kg day$^{-1}$ vs. complex mix = 0.37 kg day$^{-1}$) was much less than during the spring and summer grazing period it is hard to imagine that any animal gains could have been maintained with such low fall forage qualities (Figs. 6, 7, 8 and 9). Similar percent %OMD, %ADF and %NDF fall forage qualities have been reported by Abouguendia (1998). However, the %CP values we reported were lower and quite consistent for all three years, but the reason for these results was unclear. Abouguendia (1998) reported mean CP values for cool and warm season grasses from July to September ranging from 8.7 to 7.2% and 8.6 to 6.6% CP, respectively. Clarke and Tisdale (1945) also reported higher CP values for similar grass species and stages of maturities. A possible explanation for reported CP differences may be due to sampling procedure, site and environmental differences among the research studies. The ability of the grazing animal to selectively graze higher forage quality grasses and legume species later in the grazing season can be a major benefit of maintaining a more diverse native pasture. This study showed that a

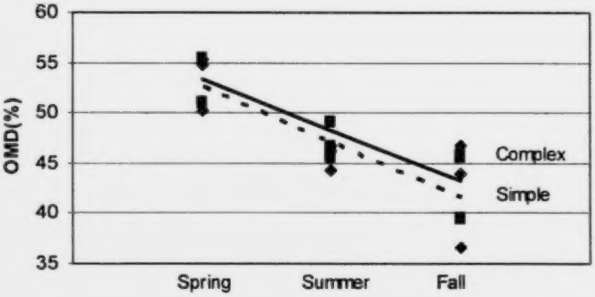

**Figure 6.** Organic matter digestibility (%) during three seasons (spring, summer and fall).

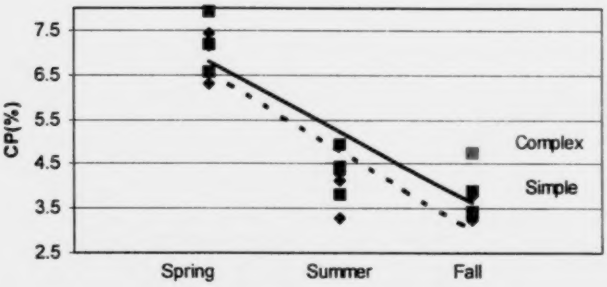

**Figure 7.** Crude protein (%) during three seasons (spring, summer and fall).

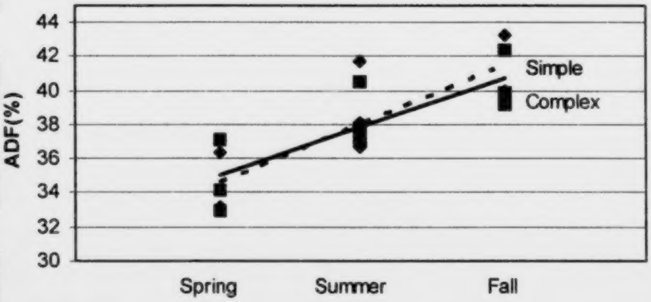

**Figure 8.** Acid detergent fibre (%) during three seasons (spring, summer and fall)

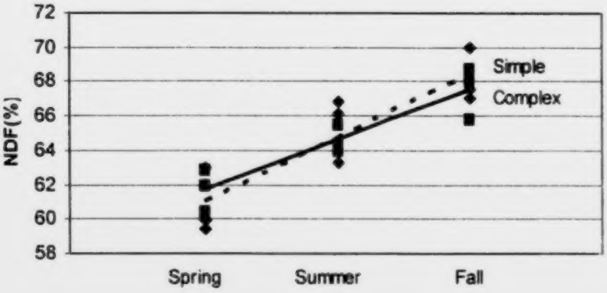

**Figure 9.** Neutral detergent fibre (%) during three seasons (spring, summer and fall)

mixture of desirable grass/forb species (i.e., cool and warm and legume species) can improve the nutritional composition of the forage and extend the grazing season.

*Grazing performance*

Actual mean pasture utilization levels in 2002, 2003 and 2004 for the low and high were 44.3% and 66% and 43.8% and 61.7% and 47.6% and 73.0%, respectively. These utilization values were within the desired target range for both low (40 to 50%) and high (60 to 75%). To achieve those pasture utilization levels the stocking rate at the low and high pasture utilization levels were 1.3 and 2.7 AU $ha^{-1}$.

No significant two or three way interactions ($P > 0.20$) were observed, therefore only significant main effects (seed mixture, utilization or year) will be reported for the dependent variables ADG and TLP. As expected significant ($P < 0.0001$) year effect occurred for ADG and TLP and year 2003 had the lowest ($P < 0.001$) ADG and TLP values compared to the other two years (2002 and 2004). The very hot and dry summer and early fall periods of 2003 greatly affected livestock performances (Appendix 1). The ADG values for 2002 and 2004 were similar, while the TLP value for 2004 was the highest ($P < 0.05$) due to the favourable moisture condition and extended grazing season that occurred (Table 6). Although not significant, an important trend was observed for the overall mean ADG ($P = 0.12$) for the complex mix which was higher than the simple and the values were 0.76 versus 0.60 ± 0.10 kg day$^{-1}$ (Table 7). These results correspond to about a 26.6% overall improvement in ADG for yearling steers grazing on the complex compared to the simple native pastures through the grazing season. It is plausible to expect better steer grazing performance on the complex pastures due to the higher specie richness (i.e., different mixture of warm and cool season grasses and shrubs) that would improve the nutritional composition of the pasture through the entire grazing season (spring to fall). In agreement, studies (Hall et al. 1982; Jackson 1999) reported that the incorporation of warm season grasses into a pasture system can improve animal performance during the summer compared with grazing only a cool season pasture. The trend ($P = 0.14$) for higher ADGs for steers grazing at the higher compared to the low pasture utilization level was also observed (Table 7), which was probably due to higher degree of forage selection and regrowth potential. Selective foraging ability (preferring some plants and avoiding others at different times throughout the grazing season) of the yearling steers has been observed on the different native pastures throughout the grazing season. During the spring and early summer period of grazing the cattle have no difficulty grazing and selecting for CWR, AWG, SWG, NTG, GNG, NWG and WWG species. Although JG starts growth very early in the spring (Pahl and Smreciu 1999) and is one of the first cool season grasses to green up it was not observed to be preferentially

**Table 6.** Least square means animal average daily gains (kg day$^{-1}$) and total livestock production (kg ha$^{-1}$) over three production years (2002 to 2004) on the native establishment study.

| | Year | | | |
|---|---|---|---|---|
| Items | 2002 | 2003 | 2004 | SE[1] |
| Average daily gain (kg/d) | 0.79b | 0.39a | 0.84b | 0.08 |
| Total live production (kg/ha) | 56.66b | 40.13a | 92.85c | 5.55 |

a-c Lsmeans in the same row with different letters are significantly different ($P<0.05$).

[1]SE = standard error

a-b Lsmeans in the same row with different letters differ ($P < 0.05$).

**Table 7.** Least square means for average daily gain (kg d$^{-1}$) for simple and complex seed mixtures that have been grazed to two different pasture utilization levels (low or high) over three production seasons (2002 to 2004) on the native establishment study.

| | Pasture utilizations | | |
|---|---|---|---|
| Seed mixtures | High | Low | Overall |
| Complex | 0.81 (0.14)[1] | 0.7 | 0.76 (0.10) |
| Simple | 0.71 | 0.49 | 0.6 |
| Overall | 0.76 (0.10) | 0.6 | |

[1] Standard error

grazed. This non-preference by the cattle would allow JG to become an increaser species. Once the grazing period reached mid summer, many of the cool season grasses were at heading and seed setting. At this time the steers on the complex native pasture selectively grazed the warm season grasses, PPC (even at the heading/seed stage) and regrowth areas from cool season grasses. In the fall grazing season, cattle continued to select for warm season grasses, however, once heading and seed setting had occurred the steers grazed these grasses less and less and appeared to start grazing NTG, GNG, NWG and WWG. Fall grazing preference of the warm season grasses in our study was observed to following this ranking LBS ≥ PSR > BG. In agreement, other studies (Rogler 1944; Vavra et al. 1977; Samuel and Howard 1982) have also observed BG to be less preferred, while LBS has been reported to be preferred to other warm season grasses and WWG during the grazing season (May to August) (Tomanek et al. 1958). The observed grazing preferences shown by yearling steers from our research studies were very much dependent upon what plant species were available for them to choose from. Therefore, grazing management and the type of seed mixtures can influence the ability of the grazing animal to select and avoid certain grasses. This in turn will influence the character and composition of the pasture and nutritional quality of the grazing diet throughout the grazing season (Wallace et al. 1972).

There was a significant seed mixture x year interaction ($P < 0.05$) for GD (Table 8). In 2002, GD for the complex seed mix was lower ($P < 0.05$) than the simple seed mix which was not surprising since the simple mix had the higher available forage production that year (simple = 2,510 kg $ha^{-1}$ and complex = 1,532 kg $ha^{-1}$). Over the three years the 2002 complex native seed mix had the lowest ($P < 0.05$) GD compared to the other two years and this was due to the lower stocking rate that was applied in 2002. For the simple native mix, for all three years, GDs did not differ ($P > 0.05$) and this may be due to the changes that were occurring in the plant community under grazing overtime. Certain grasses species in the simple mixture that were initially large contributors to the early biomass production (e.g., SWG etc.) were now declining under grazing while other species appear to be increasing (GNG, PPC, WWG etc.). Therefore, because of the diversity available, GD for the simple and complex native pastures remain constant through the two and three years of grazing.

**Table 8.** Least square means grazing days (days $ha^{-1}$) for two native mixtures (simple or complex) over three production years (2002 to 2004) on the native establishment study.

| | Year | | | |
|---|---|---|---|---|
| Seed mixtures | 2002 | 2003 | 2004 | SE[1] |
| Complex | 62.4ad | 117.9b | 122.1b | 15.7 |
| Simple | 105.4 | 130.8 | 110 | 15.7 |
| SE[1] | 15.6 | 26.8 | 19.6 | |

[1] Standard error

a-b Lsmeans in the same row with different letters differ ($P < 0.05$).

d-e Lsmeans in the same column with different letters differ ($P < 0.05$).

In comparison to other grazing studies on native pastures, Holt (1994) reported five years (1985-88) averages for TLP and GDs for beef cattle on an old native pasture in the southwest Saskatchewan of 13.4 kg ha$^{-1}$ and 30 d ha$^{-1}$, respectively. Although, results from our study are much higher than Holt (1994), it is important to realize these are results are based on recently established native pastures and only based on three years of data. Hart et al. (1988) reported similar TLP (59.5 kg h$^{-1}$) for yearling steers grazing native pastures that were producing about 1,170 kg DM ha$^{-1}$. Over a 50-year period, annual forage production estimated from standing crop after the growing season averaged 388 kg ha$^{-1}$ and ranged from 96 to 925 kg ha$^{-1}$ for a mixed prairie site (Smoliak 1986). Overall ADG for yearling steers on the different native pastures in this research study was within the range of what Hand (1996) reported to those achieved on dryland tame pastures that range from 0.7 to 1.14 kg day$^{-1}$. Hofmann et al. (1993) in a study comparing native and seeded pastures (CWG, WWG and smooth bromegrass) grazed from mid-May through September at the same stocking rate reported that the accumulated gain from the native pasture exceeded all other pastures, thus showing that native pastures can compare quite well to certain seeded pastures in animal production. Results of our study have also shown that good cattle production (i.e., ADG, TLP and GD) can occur on recently established native pastures and that these native pastures can still contribute to a sustainable agricultural systems in the Brown soil prairie region. However, it is important to realize that the native plant communities in this study are still evolving both under grazing and without grazing and further research is needed to evaluate if results for this study are maintained in the future. In addition, research is needed to better understand the geographic range of adaptation of native varieties, how native grasses combined with certain native and tame legumes can best be used to improve and extend summer and fall grazing by beef cattle and the effects that grazing management is having on the long term productivity and ecological (e.g., biodiversity) and environmental (e.g., C sequestration) sustainability of newly establishing native plant communities.

### ***Large pasture plant composition***

#### *Vegetation Analyses of Large Pastures 2002*

To date the differences observed in species composition are the result of inclusion or not in a mix of particular species. At this early date there are differences occurring between the grazed and ungrazed portions (Table LP-2). Species which have increased within the enclosures include NWG, PPC, AWG and flixweed and NWG was the dominant species for the enclosures. Species which decreased within the enclosures included WWG, PSR, SWG, GNG, barnyard grass and alfalfa. Reduction in these species may be due to sensitivity to light reduction. Weather data indicates water should have been non-limiting for most of the growing season. If this continues, diversity within the enclosures will decrease. The canopy also closed more within the enclosure with a difference of 13% from the grazed. The weed component (Table LP-3) appears evenly distributed between the two stocking densities. At this time, shrubs and legumes contribute more to the cover in high stocking density pastures while the grasses are found more in the low density stocking pastures. This may be due to decreased competition for the non-grass component. An undesirable increase under the heavier stocking density which will have to be watched is the statistically significant greater amount of sow thistle (2% vs 1%).

For DM production the simple mix has more grass and less weeds (Table LG-4). Low density pastures had less grass DM but increased weeds DM and vice versa for the high density stocking.

**Table LP-1:** Species observed and abbreviations for table LP-2.

PL = PURSLANE
WWG = W. WHEATGRASS
NWG = N. WHEATGRASS
BG = BLUE GRAMA
LBS = LITTLE BLUESTEM
SWG = SL. WHEATGRASS
FW = FLIXWEED
PPW = PROSTRATE PIGWEED
FB = FOXTAIL BARLEY
GFOX = GREEN FOXTAIL
K = KOCHIA

ST = SOW THISTLE
PPC = PURPLE PRAIRIE CLOVER
PSR = PRAIRIE SANDREED
MWG-NA = MISC WHEATGRASS NO AURICLES
NTG = NEEDLE-AND-THREAD
TG = TUMBLE GRASS
RT = RUSSIAN THISTLE
GNG = GREEN NEEDLE GRASS
BYG = BARN YARD GRASS
KW = KNOTWEED
PF = PYGMY FLOWER

TLS = THYME-LEAVED SPURGE
CWR = CANADIAN WILD RYE
AWG = AWNED WHEATGRASS
WOATS = WILD OATS
TPW = TUMBLE PIGWEED
RRPW = RED ROOT PIGWEED
WT = WILD TOMATO
GF = SPEAR LEAVED GOOSEFOOT
MD = MUSTARD
PPG = PEPPER GRASS
FBW = FIELD BINDWEED

**Table LP-2:** Species composition, top of canopy, basal, and bareground means of grazed areas and enclosures calculated from data obtained from transect sampling using a 1/4 m$^2$ quadrat 24 September to 8 October 2002. All values are expressed as % of space examined.

| ***Location/ Species*** | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
|---|---|---|---|---|---|---|---|---|---|
| Grazed | 5.3 | 8.9 | 1.3 | 1 | <0.1 | 0.2 | 7.2 | 0.4 | 0 |
| Enclosure | 2.7 | 31.3 | 1.3 | 0.7 | 0.1 | 0 | 3.1 | 0 | 0 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | WOATS | K | TG | KW | TPW |
| Grazed | 0.6 | 0.1 | 5.7 | <0.01 | 0.3 | 2.9 | 0.4 | 0.3 | 1.2 |
| Enclosure | 0.6 | 0 | 7.5 | 0 | 0.6 | 3.8 | 0 | 0 | 2 |
| | | | | | | | | | |
| Species | RRPW | PPW | FB | GFOX | FW | BWW | TLS | BYG | RT |
| Grazed | 0.3 | 0 | 1.3 | 0.7 | 1.5 | 2.5 | 8.5 | 6.5 | 1.9 |
| Enclosure | 0.1 | 0 | 0 | 0.1 | 2.5 | 2.5 | 9 | 1 | 2 |
| | | | | | | | | | |
| Species | ST | ALFALFA | OTHER | MBROME | LQ | | | | |
| Grazed | 1.5 | 8.5 | 0.4 | 1.1 | 0.1 | | | | |
| Enclosure | 1.5 | 5.4 | 1.9 | 1.9 | 0 | | | | |
| | | | | | | | | | |
| | CANOPY | BASAL | BARE GROUND | TRASH | LITTER | | | | |
| Grazed | 60.1 | 8.1 | 6.6 | 2.5 | 1.5 | | | | |
| Enclosure | 73.1 | 6.3 | 8.1 | 2.8 | 1.6 | | | | |

## *Small Plot studies*

### *Optimum seeding date study (S1)*

Environmental conditions for seedling growth were such that moisture was limiting (Fig. S1-1) although a significant difference was detected on 24 September. Early seeded plots had 13.3% soil water whereas the late seeded plots had 19.2% soil water. This may have been due to earlier growth in the plots seeded earlier. With moisture not being limiting one would expect light to be the next limiting abiotic component (Table S1-1). We noted no significant difference at the top of the canopy although the weeded plots had less light than non-weeded. This may have been due to some shading from unweeded adjacent plots. There is significant impact at the basal level though, where one finds the developing seedlings, with a 70% reduction in light.

The species seeded were all present except June grass (Table S1-3). The data was highly variable but a few can be noted in this first year of the study (Table S1-4). Little bluestem and awned wheatgrass were sensitive to the presence of weeds. Weeding had a significant impact on reducing the presence of Russian thistle, kochia, red rooted pigweed, purslane and flixweed. Fall seeding was advantageous for green needle grass and Canadian wildrye putting into question the theory that one date satisfies all species in a mix. Fall seeding also appeared to increase Russian thistle, biennial wormwood, and tumble pigweed. Bare ground increased as canopy and basal cover decreased with weeding.

The amount of weeds had a significant impact on biomass production (Table S1-5). Plots with weeds produced a little over twice the biomass as the plots which were hand weeded. At this time no effects of a mix or seeding date were detectable.

Examination of plant counts (Table S1-6) for grouping the grasses into cool and warm season, winterfat, saltbush and purple prairie clover revealed cool season grasses doing better with weeds. There was no statistical difference for the rest, although warm season grasses and saltbush were slightly better with weeds removed. Purple prairie clover and winterfat did slightly better with the weeds present, suggesting some tolerance to cover. Cool season grasses had a greater presence in the simple mixes whereas all the others were found in greater numbers in the complex, as it should be. Cool season grasses dominate the simple mix while the others are found mainly in the complex mix. The grasses overall were present in larger numbers with early spring seeding. Although not statistically significant the rest follow a similar pattern. Having said this, one cannot ignore the occurrence of increased composition of some fall seeded grasses. Also previous work has indicated winterfat was dependant on climatic conditions for time of seeding. Therefore, the better plant counts for spring seeding may be due to climatic conditions of the year.

**Table LP-3:** Grouping of species composition totals for the stocking rate factor calculated from data obtained from transect sampling using a 1/4 $m^2$ quadrat 24 September to 8 October 2002 into grassy weeds, weedy forbs, grass, shrubs and legumes. All values are expressed as % of space examined. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| Group | Low stocking density | High stocking density |
|---|---|---|
| Grassy weeds | 53 | 48.2 |
| Weedy forbs | 99.5 | 93 |
| Grass | 113.4 | 85.8 |
| Shrubs | 2.1 | 7.1 |
| Legumes | 3.5 | 7.7 |

**Table LP-4:** Dry matter yields for harvest of 24 September to 8 October for grasses and weeds. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| **Factor** | Grass Yield (g m$^{-2}$) | Pr>F | Weed Yield (g m$^{-2}$) | Pr>F |
|---|---|---|---|---|
| CV (%) | 16.1 | | 2.9 | |
| $\bar{x}$ | 75 | | 198 | |
| | | | | |
| Mix | | 0.0444 | | <0.0001 |
| Simple | 18.1 a | | 1.3 b | |
| Complex | 14.2 b | | 4.5 a | |
| | | | | |
| Stocking Density | | 0.4919 | | 0.0283 |
| Low | 15.5 | | 3.9 a | |
| High | 16.8 | | 1.9 b | |

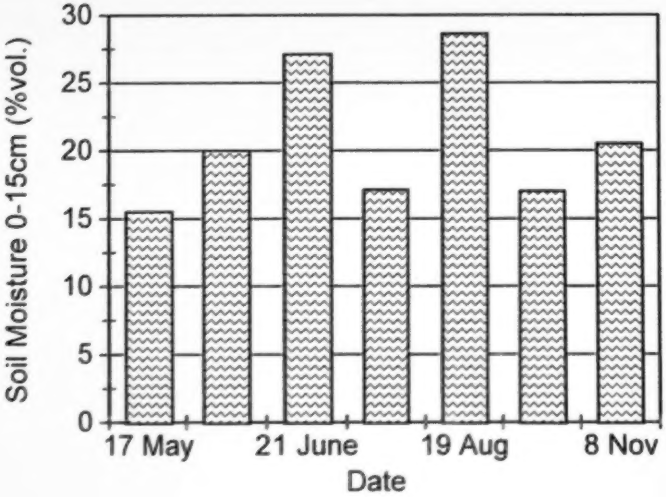

**Figure S1-1:** Average soil moisture for 0-15 cm depth 2002.

**Table S1-1**: Light readings taken 23 August 2002 at the top and ground level of canopy. Measurements are in μmol $m^{-2}$ $s^{-1}$. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | Top of Canopy | Pr>F | Ground Level | Pr>F |
|---|---|---|---|---|
| CV (%) | 7.5 | | 70.5 | |
| $\bar{x}$ | 995.8 | | 451.5 | |
| | | | | |
| Weeds | | 0.1194 | | <0.0001 |
| Present | 1008.3 | | 193.9 b | |
| Removed | 983.6 | | 709.0 a | |
| | | | | |
| Seeding Date | | 0.8046 | | 0.0308 |
| 9 May '02 | 1002.1 | | 463.3 | |
| 28 May '02 | 985.2 | | 414.6 | |
| 26 June '02 | 1014.6 | | 504.2 | |
| 8 July '02 | 962.2 | | 546.4 | |
| 9 Nov '01 | 1015.0 | | 328.9 | |
| | | | | |
| Mix | | 0.1275 | | 0.066 |
| Simple | 983.6 | | 418.1 | |
| Complex | 1008.6 | | 484.8 | |

**Table S1-2:** Species observed and abbreviations for tables S1-3, and S1-4.

DBS = DOTTED BLAZING STAR
WWG = W. WHEATGRASS
NWG = N. WHEATGRASS
BG = BLUE GRAMA
LBS = LITTLE BLUESTEM
SWG = SL. WHEATGRASS
FW = FLIXWEED
PPW = PROSTRATE PIGWEED
FB = FOXTAIL BARLEY
GFOX = GREEN FOXTAIL
K = KOCHIA
WT = WILD TOMATO
GA = GAILLARDIA
PCF = PRAIRIE CONEFLOWER
CWG = CRESTED WHEATGRASS
PPC = PURPLE PRAIRIE CLOVER
PSR = PRAIRIE SANDREED
MWG-NA = MISC WHEATGRASS NO AURICLES
NTG = NEEDLE-AND-THREAD
TG = TUMBLE GRASS
RT = RUSSIAN THISTLE
GNG = GREEN NEEDLE GRASS
BYG = BARN YARD GRASS
KW = KNOTWEED
PF = PYGMY FLOWER
PL = PURSLANE
LW = LOCOWEED
TLS = THYME-LEAVED SPURGE
CWR = CANADIAN WILD RYE
AWG = AWNED WHEATGRASS
WOATS = WILD OATS
TPW = TUMBLE PIGWEED
RRPW = RED ROOT PIGWEED
GF = SPEAR LEAVED GOOSEFOOT
TGMV = TWO GROOVED MILKVETCH
MD = MUSTARD
PPG = PEPPER GRASS
FBW = FIELD BINDWEED
BWW = BIENNIAL WORM WOOD
SW = STINKWEED

**Table S1-3:** Average compositions, determined 10 to 23 September 2002, as % for species found in plots seeded fall 2001 and spring 2002.

| Species | **WWG** | **NWG** | **BG** | **LBS** | **PPC** | **PSR** | **SWG** | **GNG** | **WF** |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 5.3 | 3.5 | 0.2 | 0.7 | 0.1 | <0.1 | 3.9 | 5.2 | <0.1 |
| | | | | | | | | | |
| Species | **NTG** | **CWR** | **AWG** | **JG** | **WOATS** | **K** | **TG** | **KW** | **TPW** |
| Mean | 0.3 | 0.1 | 3.7 | 0 | 0 | 20.5 | 0.6 | 0 | 1.5 |
| | | | | | | | | | |
| Species | **RRPW** | **FBW** | **PPG** | **PPW** | **PF** | **PL** | **GF** | **FB** | **WT** |
| Mean | 4.5 | <0.1 | 1.5 | 3 | <0.1 | 3.5 | 0.1 | 0 | 0.4 |
| | | | | | | | | | |
| Species | **MD** | **GFOX** | **FW** | **BWW** | **TLS** | **BYG** | **RT** | **SOWT** | **OTHER** |
| Mean | 0.1 | <0.1 | 3.3 | 0.4 | 0.1 | 0 | 2.3 | 0 | 0.1 |

**Table S1-4:**Mean species, canopy and bare ground compositions for factors 1) weeds and 2) Spring/fall seeding which were significantly different at the 0.05 probability level as determined using Tukey's test. (NA - not applicable).

| Species | Weeds present | Weeds removed | Spring seeding | Fall seeding |
|---|---|---|---|---|
| LBS | 0.3 | 1 | NA | NA |
| GNG | NA | NA | 1.8 | 18.6 |
| CWR | NA | NA | 0 | 0.3 |
| AWG | 1.8 | 5.6 | 2.8 | 7.2 |
| RT | 4.5 | 0.1 | 1.4 | 5.6 |
| BWW | NA | NA | 0.1 | 1.6 |
| TPW | NA | NA | 0.9 | 3.8 |
| K | 40.9 | 0.1 | NA | NA |
| RRPW | 8.1 | 0.5 | NA | NA |
| PL | 6.6 | 0.5 | NA | NA |
| FW | 6.1 | 0.5 | NA | NA |
| | | | | |
| CANOPY | 84.4 | 43.5 | 61.4 | 74.1 |
| Bare ground | 15.6 | 56.5 | 38.6 | 25.9 |

**Table S1-5:** Total dry matter yields per meter square for seral stages seeding. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | Yield (g m$^{-2}$) | Pr>F |
|---|---|---|
| CV (%) | 84.5 | |
| Mean | 198.4 | |
| | | |
| Weeds | | <0.0001 |
| Present | 354.2 a | |
| Removed | 42.6 b | |
| | | |
| Seeding Date | | 0.5986 |
| 9 May '02 | 186.1 | |
| 28 May '02 | 181.4 | |
| 26 June '02 | 235.4 | |
| 8 July '02 | 181.6 | |
| 9 Nov '01 | 207.5 | |
| | | |
| Mix | | 0.8621 |
| Simple | 191.9 | |
| Complex | 204.9 | |

**Table S1-6:** Grouped plant counts, averaged across factors collected 25 July to 2 August 2002. The counts were grouped as cool season grasses(C3), warm season grasses (C4), winterfat (WF), saltbush (SB) and purple prairie clover (PPC) for analyses. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | C3 | Pr>F | C4 | Pr>F | WF | Pr>F | SB | Pr>F | PPC | Pr>F |
|---|---|---|---|---|---|---|---|---|---|---|
| CV (%) | 33.1 | | 67.7 | | 216.4 | | 500 | | 201.8 | |
| Mean | 173.8 | | 14.6 | | 0.6 | | 0.1 | | 0.7 | |
| Weeds | | 0.0159 | | 0.6895 | | 0.857 | | 0.08 | | 0.313 |
| Present | 190.2 b | | 14.1 | | 0.7 | | 0 | | 0.9 | |
| Removed | 157.5 a | | 15 | | 0.6 | | 0.2 | | 0.6 | |
| | | | | | | | | | | |
| Seeding Date | | <0.0001 | | <0.0001 | | 0.09 | | 0.822 | | 0 |
| 9 May '02 | 260.3 b | | 25.7 a | | 1.24 | | 0 | | 1.5 | |
| 28 May '02 | 319.5 a | | 31.5 a | | 1.11 | | 0.1 | | 1.8 | |
| 26 June '02 | 93.3 d | | 6.8 b | | 0.14 | | 0.1 | | 0.3 | |
| 8 July '02 | 38.6 d | | 1.5 b | | 0.14 | | 0 | | 0 | |
| 9 Nov '01 | 157.2 c | | 7.2 b | | 0.56 | | 0.1 | | 0 | |
| | | | | | | | | | | |
| Mix | | <0.0001 | | <0.0001 | | 0 | | 0.555 | | 0.546 |
| Simple | 220.8 a | | 0.8 b | | 0.1 b | | 0.1 | | 0.7 | |
| Complex | 126.8 b | | 28.3 a | | 1.2 a | | 1.2 | | 0.8 | |

### *Seral stages study (S2)*

For this study soil moistures again provide a picture of an environment not limited by moisture (Fig. S2-1). Initial readings on 17 May indicated a significantly lower soil moisture reserve for plots seeded in fall 2001 (14.9%) than spring 2002 seeded plots (16.1%). August and September reading found more moisture in unweeded plots (30.5% and 19.0%) than weeded plots (26.7% and 15.0%). This was likely due to decreased exposure of the soil surface.

Light readings indicated the only detectable difference was due to the type of mix (Table S2-1) for the top of the canopy. The basal readings indicated increased light penetration to the ground in areas where the weeds were removed. The differences associated with seeding mix are most likely due to composition of the canopy.

The species compositions were highly variable. Most species seeded were present with the exception of June grass and saltbush (Table S2-3). Most of the grasses made up more of the compositions if weeds were absent, strongly indicating some form of weed control is required (Table S2-4). Winterfat in this study required weed control but seeding date had no significant impact. Western wheatgrass, blue grama, purple prairie clover, and slender wheatgrass made up more of the composition if seeded in spring. Green needle grass continued to show a preference for fall seeding. Annual weeds such as kochia, red root pigweed, prostrate pigweed and flixweed were significantly decreased with hand weeding. Very little bare ground existed when weeds were present, but increased to 50% while both top of canopy and basal decreased by 48 to 32% respectively when weeded. Fall or spring seeding did not have an impact on amount of canopy, basal or bare ground cover.

Total dry matter yield was strongly influenced by the weed component (Table S2-5). Plots with weeds present had approximately 7 times the biomass. Simple (253.7 gm$^{-2}$) early (231.0 gm$^{-2}$) mixes had greater biomass that complex (191.9 gm$^{-2}$) or late (177.6 gm$^{-2}$) mixes. One should note though this was the first year of seeding and therefore late and early seral stage plots do not have a full complement of species yet.

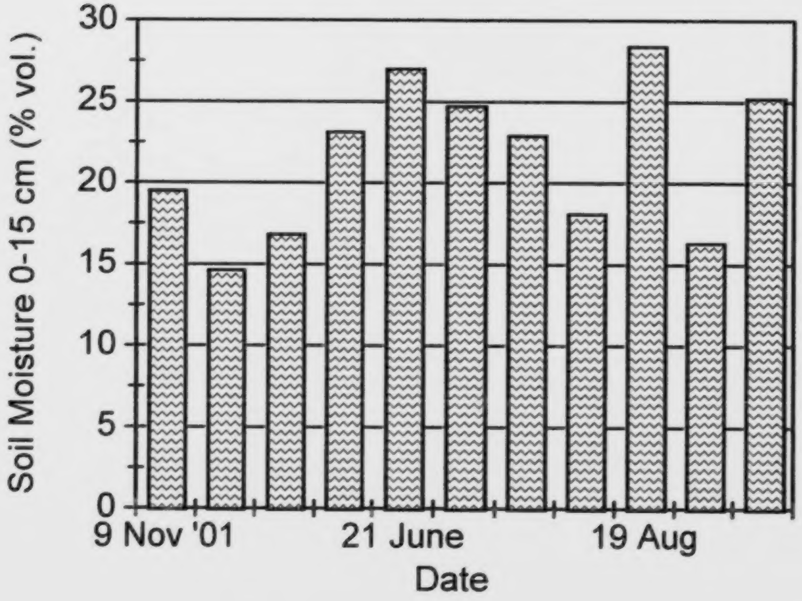

**Figure S2-1:** Average soil moisture for 0-15 cm depth 2002.

**Table S2-1**: Light readings taken 23 August 2002 at the top and ground level of canopy. Measurements are in µmol $m^{-2}$ $s^{-1}$. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | Top of canopy | Pr>F | Ground Level | Pr>F |
|---|---|---|---|---|
| CV (%) | 3.5 | | 33.7 | |
| Mean | 1153.7 | | 545.5 | |
| | | | | |
| Weeds | | 0.2309 | | <0.0001 |
| Present | 1152.5 | | 133.5 b | |
| Removed | 1144.0 | | 943.3 a | |
| | | | | |
| Seeding Date | | 0.2913 | | 0.7837 |
| Spring '02 | 1143.3 | | 533.3 | |
| Fall '01 | 1153.2 | | 543.6 | |
| | | | | |
| Mix | | 0.0517 | | 0.0252 |
| Simple | 1130.3b | | 498.9ab | |
| Complex | 1144.4ba | | 549.8ab | |
| Early seral | 1161.4a | | 492.9b | |
| Late seral | 1157.0a | | 612.1a | |

**Table S2-2:** Species observed and abbreviations for tables S2-3 and S2-4.

PL = PURSLANE
WWG = W. WHEATGRASS
NWG = N. WHEATGRASS
BG = BLUE GRAMA
LBS = LITTLE BLUESTEM
SWG = SL. WHEATGRASS
FW = FLIXWEED
PPW = PROSTRATE PIGWEED
FB = FOXTAIL BARLEY
GFOX = GREEN FOXTAIL
K = KOCHIA

WT = WILD TOMATO
PPC = PURPLE PRAIRIE CLOVER
PSR = PRAIRIE SANDREED
MWG-NA = MISC WHEATGRASS NO AURICLES
NTG = NEEDLE-AND-THREAD
TG = TUMBLE GRASS
RT = RUSSIAN THISTLE
GNG = GREEN NEEDLE GRASS

BYG = BARN YARD GRASS
KW = KNOTWEED
PF = PYGMY FLOWER

TLS = THYME-LEAVED SPURGE
CWR = CANADIAN WILD RYE
AWG = AWNED WHEATGRASS
WOATS = WILD OATS
TPW = TUMBLE PIGWEED
RRPW = RED ROOT PIGWEED
FBW = FIELD BINDWEED
GF = SPEAR LEAVED GOOSEFOOT
MD = MUSTARD
PPG = PEPPER GRASS

**Table S2-3:**Mean compositions, determined 9 to 23 September 2002, as % for species found in plots seeded fall 2001 and spring 2002.

| **Species** | **WWG** | **NWG** | **BG** | **LBS** | **PPC** | **PSR** | **SWG** | **GNG** | **WF** |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 4.1 | 2.41 | 1.1 | 0.2 | <0.1 | 0.6 | 11.6 | 3.7 | 0.2 |
| **Species** | **NTG** | **CWR** | **AWG** | **JG** | **PCF** | **DBS** | **TGMV** | **GA** | **LW** |
| Mean | 0.5 | 0.1 | 2.4 | 0 | 0.1 | <0.1 | 0.1 | 0.1 | <0.1 |
| **Species** | **WOATS** | **K** | **TPW** | **RRPW** | **PPG** | **PPW** | **PL** | **BWW** | **MD** |
| **Mean** | 0 | 23.4 | 0.3 | 5.6 | 1.7 | 0.7 | 1.4 | 0.2 | 0.2 |
| **Species** | **FW** | **WBW** | **RT** | | | | | | |
| **Mean** | 3.5 | 0.8 | 7.2 | | | | | | |

**Table S2-4**: Averages of species, top of canopy, ground level canopy and bare ground compositions for factors 1) weeds and 2) Spring/fall seeding which were significantly different at the 0.05 probability level as determined using Tukey's test. (NA - not applicable).

| Species | Weeds present | Weeds absent | Spring seeding | Fall seeding |
|---|---|---|---|---|
| WWG | 0.8 | 7.4 | 5.4 | 2.8 |
| NWG | 0.3 | 4.5 | NA | NA |
| BG | 0 | 2.1 | 1.4 | 0.7 |
| LBS | 0 | 0.3 | NA | NA |
| PPC | 0 | 0.1 | 0.1 | 0 |
| SWG | 3.6 | 19.7 | 13.8 | 9.5 |
| GNG | 0.6 | 6.8 | 1.8 | 5.6 |
| WF | 0 | 0.4 | NA | NA |
| NTG | 0 | 1.1 | NA | NA |
| AWG | 1 | 3.8 | NA | NA |
| K | 46.7 | 0 | NA | NA |
| RRPW | 11.1 | 0.2 | NA | NA |
| PPG | 3.5 | 0 | NA | NA |
| FW | 7 | 0 | NA | NA |
| | | | | |
| TOP CANOPY | 94 | 49.7 | 74.4 | 69.3 |
| BASAL CANOPY | 13.8 | 8.1 | 12.3 | 9.6 |
| BARE GROUND | 6 | 50.3 | 25.6 | 30.7 |

**Table S2-5**: Total dry matter yields per meter square for seral stages seeding. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | Yield (g $m^{-2}$) | Pr>F |
|---|---|---|
| CV (%) | 49.5 | |
| Mean | 209 | |
| | | |
| Weeds | | <0.0001 |
| Present | 364.3 a | |
| Removed | 53.6 b | |
| | | |
| Seeding date | | 0.1789 |
| Spring | 198.9 | |
| Fall | 219 | |
| | | |
| Mix | | 0.0001 |
| Simple | 253.7 ab | |
| Complex | 191.9 ab | |
| Early | 231.0 b | |
| Late | 177.6 a | |

### *Large Pasture Studies 2003*

Due to the extremely dry hot conditions of 2003 overall production decreased from the previous year. The greatest reduction occurred within the weedy annuals (Table LP(03)-2). Canopy and basal cover did not decrease due to a shift in composition to more grass (Table LP(03)-2 and Figure LP(03)-1). Grass generally thought to be more drought resistant. The higher stocking density had its greatest impact on the almost complete elimination of non-grass component (Figure LP(03)-1).The overall species richness as determined by the Simpson's Index was 0.7 (Table LP(03)-2).

The impact of the drought conditions appeared to have had an overriding effect on dry matter production with statistically significant differences ($\alpha = 0.05$) occurring for the mix or stocking density factors (LP(03)-3). The simple mix has more grass and weeds. The low density pastures continued to have less grass dry matter but increased weed dry matter and vice versa for the high density stocking.

**Table LP(03)-1:** Species observed and abbreviations for table LP(03)-2.

WT = WILD TOMATO
WWG = W. WHEATGRASS
NWG = N. WHEATGRASS
BG = BLUE GRAMA
LBS = LITTLE BLUESTEM
SWG = SL. WHEATGRASS
FW = FLIXWEED
PPW = PROSTRATE PIGWEED
FB = FOXTAIL BARLEY
GFOX = GREEN FOXTAIL
K = KOCHIA

ST = SOW THISTLE
PPC = PURPLE PRAIRIE CLOVER
PSR = PRAIRIE SANDREED
MWG = MISC WHEATGRASS NO AURICLES
NTG = NEEDLE-AND-THREAD
TG = TUMBLE GRASS
RT = RUSSIAN THISTLE
GNG = GREEN NEEDLE GRASS

BYG = BARN YARD GRASS
KW = KNOTWEED
PF = PYGMY FLOWER

TLS = THYME-LEAVED SPURGE
CWR = CANADIAN WILD RYE
AWG = AWNED WHEATGRASS
WOATS = WILD OATS
TPW = TUMBLE PIGWEED
RRPW = RED ROOT PIGWEED
PL = PURSLANE
GF = SPEAR LEAVED GOOSEFOOT
MD = MUSTARD
PPG = PEPPER GRASS
FBW = FIELD BINDWEED

**Table LP(03)-2:** Species composition, top of canopy, basal, and bareground means of grazed areas calculated from data obtained from transect sampling using a 1/4 $m^2$ frame 17 to 28 October 2003. All values are expressed as % of space examined.

| *Location/Species* | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
|---|---|---|---|---|---|---|---|---|---|
| Grazed | 3.1 | 5 | 2 | 1.9 | 0.01 | 0.1 | 6.3 | 0.4 | 0 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | K | TG | TPW | FB | GFOX |
| Grazed | 0.6 | 0.2 | 5.3 | 0.3 | 0.7 | 1.3 | 0.4 | 1.11 | 0.01 |
| | | | | | | | | | |
| Species | FW | RT | WO | CWG | MWG | MG | GWEEDS | FWEEDS | |
| Grazed | 0.1 | 0.3 | 0.4 | 0.2 | 6.7 | 0.8 | 3.1 | 1.6 | |
| | | | | | | | | | |
| Environmental Factors | Top Canopy | Basal Cover | Litter | Bare ground | | Simpson's Index | | | |
| Grazed | 60.9 | 13.4 | 24.1 | 39.1 | | 0.7 | | | |

**Figure LP(03)-1:** Grouping of species composition totals, for the stocking rate factor calculated from data obtained from transect sampling using a 1/4 $m^2$ frame 24 September to 8 October 2002 and 17 to 28 October 2003 into grassy weeds, weedy forbs, grass, shrubs and legumes. All values are expressed as % of space examined. Values were not significantly different for 2002 but all were significantly different for 2003 at the 0.05 level as determined by the Tukey's test.

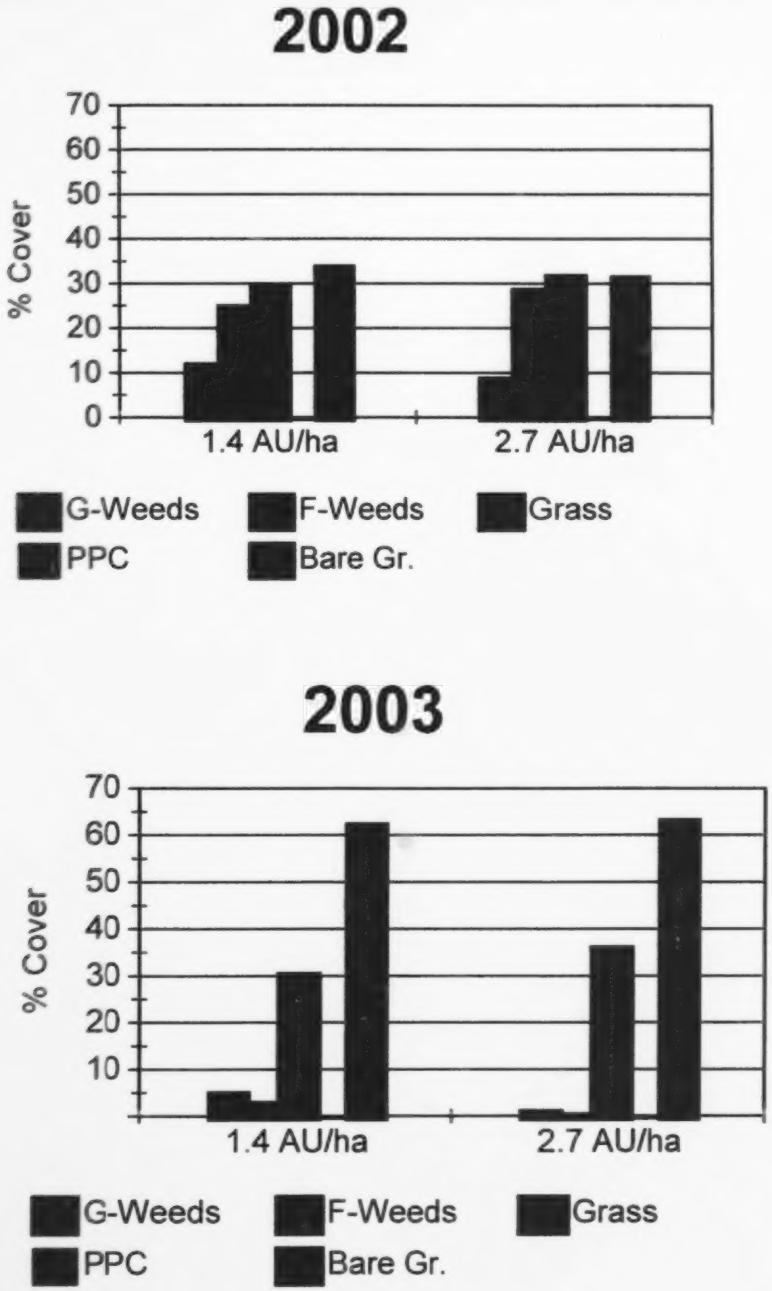

**Table LP(03)-3:** Dry matter yields for harvest of 17 to 28 October for grasses and weeds. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| **Factor** | Grass Yield (g $m^{-2}$) | Pr>F | Weed Yield (g $m^{-2}$) | Pr>F |
|---|---|---|---|---|
| CV (%) | 80.1 | | 438 | |
| MEAN | 41.2 | | 1.7 | |
| | | | | |
| Mix | | 0.2604 | | 0.3799 |
| Simple | 46 | | 2.1 | |
| Complex | 35.2 | | 1.2 | |
| | | | | |
| Stocking Density | | 0.1127 | | 0.1124 |
| Low | 38 | | 2.6 | |
| High | 45.2 | | 0.6 | |

### *Small Plot studies 2003*

### S1 - Optimum seeding date study

The year 2003 was the complete opposite of 2002 when it came to moisture. Soil moisture was initially adequate but failed to be replenished until the fall period. Soil moistures for both sites in 2003 show the adequate moisture in May with the start of the decline in June with replenishment starting in September (Figure S1(03)-1). In the plots with only growth from 2003 there were no differences between weeding, seeding date or mix. In the plots with a second years growth the June readings indicated there was more moisture in plots with weeds indicating less withdrawal of this resource. The September reading shows the same trend but it was no longer statistically significant ($\alpha = 0.05$).

Light readings for 2003 were higher than 2002 indicating greater light and a more open canopy (Table S1(03)-1). For the first year of growth plots the only factor which had an effect was the weeded vs. non-weeded. Some shading occurred from adjacent vegetation in plots with weeds removed at the top of the canopy and a greater amount of light reached the soil surface. The opposite can be seen in plots with the second year's growth. Plots, which had the weeds removed the previous year, were utilizing more light with a resulting decrease of light at the soil surface whereas the weedy plots had greater light and more open canopy. The November 2001 and May 2002 seeded plots had less light at the soil surface, indicating greater utilization for 2003.

The plant composition data continued to be highly variable. Plant compositions of the plots with two year's growth (Table S1(03)-3) show an increase of species with an affinity for open canopies and possibly some drought tolerance such as western wheatgrass, green needle grass, needle and thread grass, Canadian wildrye, and awned wheatgrass. Most of the annual colonizers decreased in composition except pepper grass and flixweed both of the mustard family. Plots within the site seeded in 2003 (Table S1(03)-4) had a much decreased seeded plant composition. They were dominated by annual colonizers. The main species were field bindweed, pepper grass, prostrate pigweed, Russian thistle, flixweed and lamb's quarter, a different mix than last year. The date of seeding continued to have a significant effect on two grass species with second year of growth (Table S1(03)-5). Western wheatgrass plots seeded in early spring continued to do better while fall seeded green needle grass did better. Fall seeding in 2002 increased the contribution of green needle grass, awned wheatgrass and June grass. Winterfat continued to do best with an early spring seeding. Pepper grass preferred plots seeded in late June. The species richness (Table S1(03)-6) was greater for the weeded plots indicating more species were able to co-exist for the site with first year growth but no difference was noted for second year growth plots. The second year growth plots also had decreased species richness due to fewer weeds. Seeding date comparisons for similarity using Jaccard's Similarity Index indicated an approximately 60% similarity for both sites. There was only a 33% similarity for simple and complex mixes for first year growth but the site with second year's growth had a 60% similarity, suggesting the possibility the two mixes may become more similar as time progresses. Dry conditions in the establishment year may be the result or the ongoing successional process may be the factor resulting in the similarity index differences in the two sites.

The amount of weeds again had a significant impact on biomass production for the site established in 2003. Weed dry matter production was 137.2 g m-$^{2}$ for plots with weeds and 0.0 g m-$^{2}$ for weeded plots. The grass dry matter yield was equally significant with 0.8 g m-$^{2}$ for weeded plots versus 0.0 g m-$^{2}$ for unweeded. These yields are markedly less than last year's yields due to the extremely dry conditions. As stated earlier, due to time and uncooperative weather dry matter yields were unavailable for the second year of growth site.

For material collected in 2002 the nutritional characteristics were as follows (Table S1(03)-7): In the weeded portions of the plots there was a greater amount of digestible organic matter, although less organic matter, less acid and neutral detergent digestible fibre, greater crude protein and difference in total phosphorous content. The annual weeds were contributing more material but of lower nutritional quality in the fall. The earlier seeding date (fall, early spring) provided more organic matter, material with greater digestibility, lower acid detergent fibre but greater neutral detergent fibre with slightly higher crude protein for the fall harvest. These increases correlate with increased germination of seeded species. The simple mix had greater organic matter, better digestibility and greater percentage neutral detergent fibre in fall. Looking at Table S1-6 we note greater numbers of cool season grasses in the simple mix with more warm season grasses in the complex. The weather was cooler than normal which may have resulted in increased fibre production among the warm season grasses as well as the greater amount of weeds (Table S1-3, S1-5).

**Figure S1(03)-1:** Average soil moisture for 0-15 cm depth for 2003 for sites with first year growth and second year growth.

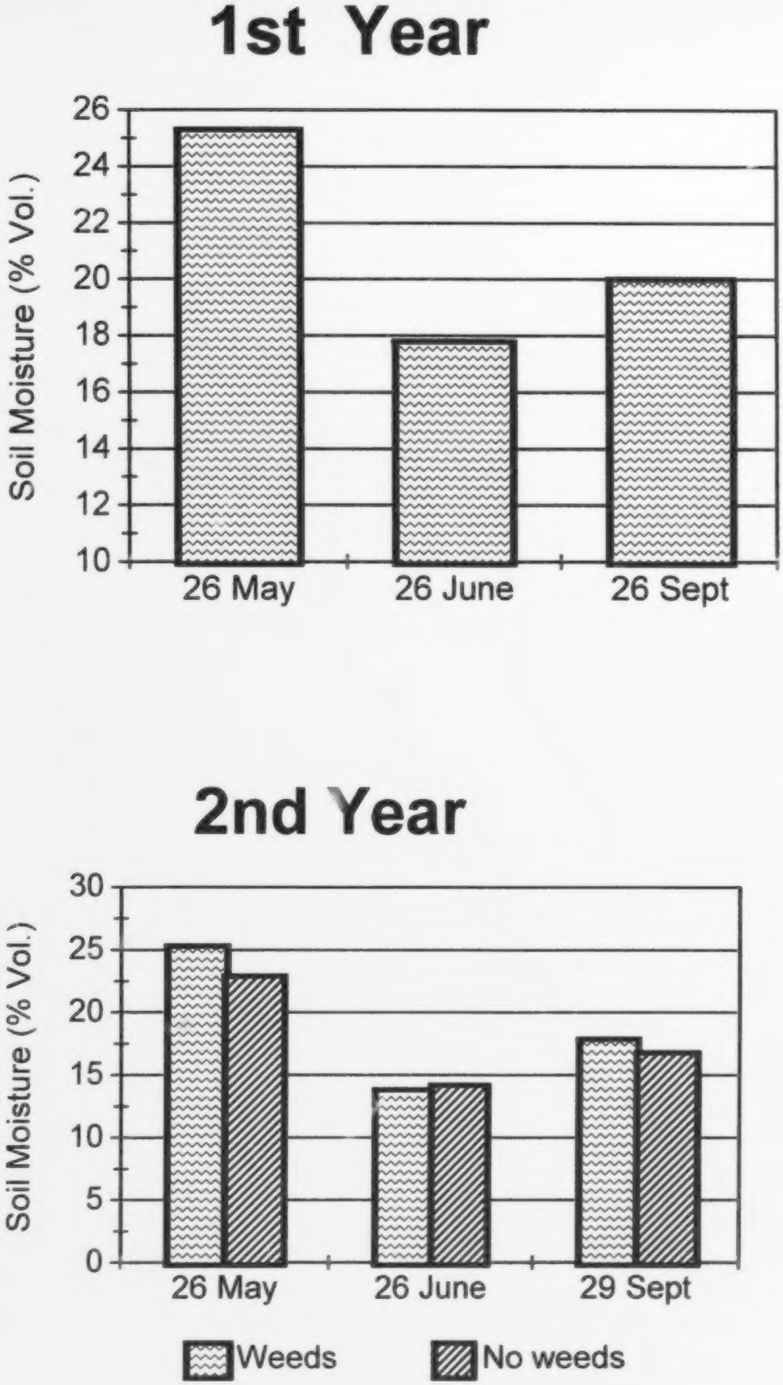

**Table S1(03)-1**: Light readings taken 25 August 2003 at the top and ground level of canopy for sites with first and second year growth. Measurements are in $\mu mol\ m^{-2}\ s^{-1}$. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | **First Year** | | | | | **Second Year** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Top of Canopy | Pr>F | Ground Level | Pr>F | | Top of Canopy | Pr>F | Ground Level | Pr>F |
| CV (%) | 2.8 | | 22.9 | | CV (%) | 4.1 | | 36.7 | |
| MEAN | 1466.6 | | 1244.5 | | MEAN | 1354.3 | | 739.2 | |
| | | | | | | | | | |
| Weeds | | 0.0015 | | <0.0001 | Weeds | | 0.2231 | | 0 |
| Present | 1481.0 a | | 1046.0 b | | Present | 1347.4 | | 846.6 a | |
| Removed | 1452.3 b | | 1443.0 a | | Removed | 1361.3 | | 631.9 b | |
| | | | | | | | | | |
| Seeding Date | | 0.3294 | | 0.3084 | Seeding Date | | 0.6448 | | 0.0097 |
| 29 Apr ‘03 | 1468.8 | | 1123.3 | | 9 May ‘02 | 1360.1 | | 591.2 b | |
| 27 May ‘03 | 1469.1 | | 1273.9 | | 28 May ‘02 | 1339.8 | | 670.8 ab | |
| 20 June ‘03 | 1447.8 | | 1337.1 | | 26 June ‘02 | 1371.8 | | 929.1 a | |
| 25 June ‘03 | 1450.4 | | 1312.7 | | 8 July ‘02 | 1375.8 | | 831.5 ab | |
| 4 Oct ‘02 | 1468.6 | | 1208.4 | | 9 Nov ‘01 | 1328.7 | | 637.5 b | |
| 24 Oct ‘02 | 1495.0 | | 1211.6 | | | | | | |
| Mix | | 0.9415 | | 0.1125 | Mix | | 0.7919 | | 0.2217 |
| Simple | 1466.2 | | 1197.5 | | Simple | 1352.7 | | 750.9 | |
| Complex | 1467.1 | | 1291.5 | | Complex | 1355.9 | | 727.9 | |

**Table S1(03)-2:** Species abbreviations.

MWG = MISC. WHEATGRASS
WWG = W. WHEATGRASS
NWG = N. WHEATGRASS
BG = BLUE GRAMA
LBS = LITTLE BLUESTEM
SWG = SL. WHEATGRASS
FW = FLIXWEED
PPW = PROSTRATE PIGWEED
FB = FOXTAIL BARLEY
GFOX = GREEN FOXTAIL
K = KOCHIA
TGMV = TWO GROOVED MILKVETCH
G = GAILLARDIA
MG = MISC. GRASS
GB = GOLDEN BEAN

PPG = PEPPER GRASS
PPC = PURPLE PRAIRIE CLOVER
PSR = PRAIRIE SANDREED
LQ = LAMB'S QUARTER
NTG = NEEDLE-AND-THREAD
TG = TUMBLE GRASS
RT = RUSSIAN THISTLE
GNG = GREEN NEEDLE GRASS
BYG = BARN YARD GRASS
KW = KNOTWEED
PF = PYGMY FLOWER
PL = PURSLANE

LW = LOCOWEED
BBW = BUCK WHEAT
DBS = DOTTED BLAZING STAR

TLS = THYME-LEAVED SPURGE
CWR = CANADIAN WILD RYE
AWG = AWNED WHEATGRASS
WOATS = WILD OATS
TPW = TUMBLE PIGWEED
RRPW = RED ROOT PIGWEED
GF = SPEAR LEAVED GOOSEFOOT
PCF = PRAIRIE CONEFLOWER
MD = MUSTARD
WT = WILD TOMATO
FBW = FIELD BINDWEED
BWW = BIENNIAL WORM WOOD

SW = STINKWEED
RT = RED TOP
CWG = CRESTED WHEATGRASS

**Table S1(03)-3:** Average compositions, determined 2 to 15 September 2003, as % for species found in plots seeded fall 2001 and spring 2002 (2nd year of growth).

| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 7.7 | 1.2 | 0.1 | 0.1 | <0.1 | 0 | 1.7 | 6.3 | <0.1 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | WOATS | K | TG | KW | TPW |
| Mean | 0.6 | 0.3 | 8.3 | <0.1 | 0 | 10.3 | 0.6 | 0 | 1.5 |
| | | | | | | | | | |
| Species | RRPW | FBW | PPG | PPW | PF | PL | GF | FB | WT |
| Mean | 4.5 | 0.1 | 9.7 | 3 | 0.3 | 3.5 | <0.1 | <0.1 | 0.4 |
| | | | | | | | | | |
| Species | MD | GFOX | FW | BWW | TLS | BYG | RT | SOWT | |
| Mean | 0.1 | <0.1 | 16.6 | 0.4 | 0.1 | 0 | 0.2 | 0 | |
| | | | | | | | | | |
| Species | MWG | MG | TG | CFB | | | | | |
| Mean | 5.5 | <0.1 | 2.6 | 0.3 | | | | | |

**Table S1(03)-4:** Average compositions, determined 15 to 19 September 2002, as % for species found in plots seeded fall 2002 and spring 2003 (1st year of growth) .

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
| Mean | 0.3 | 0.1 | 0 | 0 | <0.1 | 0 | 0.6 | 0.2 | <0.1 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | WOATS | K | TG | KW | TPW |
| Mean | <0.1 | 0 | 0.1 | <0.1 | 0 | 0 | 0.6 | <0.1 | <0.1 |
| | | | | | | | | | |
| Species | RRPW | FBW | PPG | PPW | PF | PL | GF | FB | WT |
| Mean | <0.1 | 4.3 | 1.5 | 3.7 | <0.1 | 0.6 | 0.1 | 0 | 0.7 |
| | | | | | | | | | |
| Species | MD | RT | FW | BWW | TLS | LQ | WBW | MWG | MG |
| Mean | 0.1 | 9.8 | 3.7 | 0.4 | 0.2 | 1.8 | 0.3 | 0.1 | 0.1 |

**Table S1(03)-5:** Average compositions for seeding dates as % for species found in plots for first and second years growth of western wheatgrass (WWG), green needle grass (GNG), awned wheatgrass (AWG), June grass (JG), winterfat (WF) and prostrate pigweed (PPW). Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | Second Year of Growth | |
|---|---|---|
| Seeding Date /Species | WWG | GNG |
| 9 May '02 | 14.4 a | 8.3 ab |
| 28 May '02 | 17.2 a | 3.5 b |
| 26 June '02 | 5.1 b | 2.5 b |
| 8 July '02 | 1.0 b | 1.1 b |
| 9 Nov '01 | 8.2 ab | 21.8 a |
| | | |

| | First Year of Growth | | | | |
|---|---|---|---|---|---|
| Seeding Date /Species | GNG | AWG | JG | WF | PPW |
| 29 Apr '03 | 0.0 b | 0.0 b | 0.0 b | 0.2 a | 0.0 b |
| 27 May '03 | 0.0 b | 0.0 b | 0.0 b | 0.1 a | 0.0 b |
| 20 June '03 | 0.0 b | 0.0 b | 0.0 b | 0.0 b | 12.3 a |
| 25 June '03 | 0.0 b | 0.0 b | 0.0 b | 0.0 b | 9.9 a |
| 4 Oct '02 | 0.8 a | 0.0 b | 0.0 b | 0.0 b | 0.1 b |
| 24 Oct '02 | 0.6 a | 0.4 a | 0.1 a | 0.0 b | 0.0 b |

**Table S1(03)-6:** Simpson's index for species richness and Jaccard's Similarity Index for first year of growth (seeded 2003) and second year of growth (seeded 2002).

| | First year of growth | | Second year of growth | |
|---|---|---|---|---|
| | | | | |
| Simpson's Index | | | | |
| Mean | 0.9 | | 0.75 | |
| Weeded | 0.99 | | 0.76 | |
| Unweeded | 0.81 | | 0.74 | |
| | | | | |
| Jaccard's Similarity Index | | Std. Deviation | | Std. Deviation |
| Fall vs early spring seeding | 59.46 | 8.04 | 63.99 | 16.79 |
| Fall vs late spring seeding | 59.78 | 15 | 62.57 | 17.38 |
| Simple vs complex mix | 33.28 | 8.48 | 59.66 | 6.78 |

**Table S1(03)-7:** Nutritional characteristics (organic matter (OM), organic matter digested (OMD), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP) and total phophorous (TP)) for material collected in 2002, one year of growth. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | OM | OMD | ADF | NDF | CP | TP |
|---|---|---|---|---|---|---|
| CV (%) | 2.1 | 11.9 | 11.9 | 8.2 | 22.1 | 19.2 |
| MEAN | 87.1 | 53.4 | 33.8 | 52.1 | 12.9 | 0.2 |
| | | | | | | |
| Weeds (Pr>F) | <0.0001 | 0.4065 | <0.0001 | <0.0001 | 0.0001 | 0.172 |
| Present | 88.8 a | 50.8 b | 36.7 a | 53.3 a | 1.8 b | 0.19 |
| Removed | 84.2 b | 58.0 a | 28.9 b | 50.1 b | 2.5 a | 0.2 |
| | | | | | | |
| Seeding Date (Pr>F) | <0.0001 | <0.0001 | 0.0084 | 0 | 0.348 | 0.66 |
| 9 May '02 | 87.9 a | 56.1 a | 33.2 | 52.0 ab | 13.9 | 0.2 |
| 28 May '02 | 88.3 a | 55.9 a | 33.4 | 51.9 ab | 13.5 | 0.2 |
| 26 June '02 | 80.1 b | 47.0 b | 31.6 | 47.5 b | 12.6 | 0.19 |
| 8 July '02 | 87.6 a | 49.6 ab | 37.1 | 52.1 ab | 11.1 | 0.21 |
| 9 Nov '01 | 88.2 a | 57.9 a | 32.7 | 54.7 a | 13.7 | 0.18 |
| | | | | | | |
| Mix (Pr>F) | <0.0001 | <0.0001 | 0.1987 | 0.0024 | 0.7235 | 0.6011 |
| Simple | 88.4 a | 54.7 a | 33.7 | 52.7 a | 13.1 | 0.19 |
| Complex | 85.8 b | 52.1 b | 33.9 | 51.4 b | 12.6 | 0.2 |

**S2 - Seral stages study**

For 2003, the year started with adequate soil moisture at the 0-15 cm depth (Figure S2(03)-1) with an increase with June rains but seedlings were below the permanent wilting points with soil moisture at or below 8% in July and August. It was during this period when record breaking high temperatures were reached with no significant moisture received until September. In September, soil moisture improved as indicated with readings around 17%. No differences were seen for seeding mix or weeding effects when readings were taken. There was some variation but not biologically significant with differences less than 1%. The aforementioned observations were the same for both sites.

Light readings for the top of the canopy did not differ with the site of second year of growth having a mean of 1225.4 μmol $m^{-2}$ $s^{-1}$ and the site with first of growth 1268.1 μmol $m^{-2}$ $s^{-1}$. The basal light did differ significantly for weeded and non weeded plots for both sites (Figure S2(03)-2) but not seed mix or time of seeding. In the plots with second year growth we see a shift in light acquisition from weeds to seeded plants. Comparing last year's readings (Table S2-1) and this year's reading for first year growth with second year growth plots one notes similar response for first year growth for both years. A shift from annual plant production to perennial plant production can be implied.

The species compositions were again highly variable. Most species seeded were present with the exception of saltbush (Table S2(03)-1) for the site with second year's growth. Seeded species dominated the compositions with western wheatgrass, slender wheatgrass, green needle grass, needle and thread grass, awned wheatgrass and June grass making the largest gains. A number of the seeded native forbs were present (prairie cone flower, two groove milkvetch, gaillardia and golden bean). Winterfat decreased while the rest slightly increased or remained the same. Most annual species declined with exception of pepper grass. For the site with first year's growth annual species (Table S2(03)-2) dominated but the annual mix differed from 2002 (Table S2-3). The most common annual species were lamb's quarter, kochia, knotweed, flixweed and field bindweed. Canadian wildrye, June grass and salt bush were missing of the species seeded and very few native perennial forbs were present. Proportions of the composition were way down from the previous year first year's growth for all species; another indication of the extreme conditions encountered by the seedlings. Differences in the species were due to the mix that was seeded. If the species had not been seeded it did not occur and vice versa thus resulting in a comparison of presence and absence.

The time of seeding (Table S2(03)-3) continued to have an significant effect for little bluestem, awned wheatgrass, June grass and green needle grass in the second year of growth; little bluestem, awned wheatgrass, and June grass all preferring spring seeding. June grass appears to require a full year or hot dry conditions before being present. A further indication of extreme environment in which the seeded species emerged can be seen in time of seeding benefit for species seeded in fall of 2002. Slender wheatgrass, western wheatgrass, green needle grass, northern wheatgrass, needle and thread grass, and awned wheatgrass all made up a larger proportion of the stand if seeded in fall. Slender wheatgrass, western wheatgrass, and awned wheatgrass previously had contributed more in the first year if seeded in spring (Table S2-4).

Species richness, calculated using Simpson's Index, for the site with first year's growth had only a significant difference ($\alpha = 0.05$) for the weeded/non-weeded comparison. Plots with weeds had an index value of 0.81 while weeded plots had a index value of 0.99

indicating seeding resulted in greater species richness. For the second year's growth site species richness was lower with a mean index value of 0.77 (Table S2(03)-4). A similar trend was noted in Table S1(03)-6. This value is also similar for the value obtained for the large pastures (Table LP(03)-2).The species mix with the highest index value was the species mix generated by early seral species seeded in year one with late seral species seeded in year 2 (Table S2(03)-3). The lowest species richness value was obtained for the late seral species seeded in year 1 and early seral species seeded in year 2. The other seeded mixes were intermediate. This may be an initial indication for splitting seeding years for species occurring in different phases of succession.

When comparing the seeded species mixes for similarity, by calculating Jaccard's Index of Similarity, no strong differences were noted. The site in its second year of development had a similarity of 47.8% with a standard deviation of 13.1 while the site in its first year of development had a similarity of 45.4% with a standard deviation 7.2.

For 2003, dry matter yields were only affected by the presence/absence of weeds for both sites for both weeds and grasses (Table S2(03)-5). Weed dry matter was greatest were no weeding occurred and in the first year of growth, as seen in previous experiments reported in 2003. Grass dry matter was greatest were there were no weeds. In the site with first year's growth only plots with weed removed had any grass production at the time of harvest. By the second year of growth weed production dropped with grass production surpassing weed production. This is also indicated by decreased basal light as discussed previously.

The presence of weeds had the same effect as discussed in the previous experiment (S1) on fall nutritional quality (Table S2(03)-6) of samples taken in 2002. The plots with the weeds removed had a greater phosphorous content. Fall seeding for this experiment failed to result in any statistically significant differences ($\alpha = 0.05$) although a similar trend can be seen in experiment S1. Early seral species had greater fibre and lower crude proteins. The simple and complex mixes were intermediate with late seral species being the opposite of the early seral species. The intermediate values can be interpreted as the complex and simple seed mixes being a combination of both early and late seral species.

**Figure S2(03)-1:** Average soil moisture for 0-15 cm depth for 2003 plots with first year and second year growth.

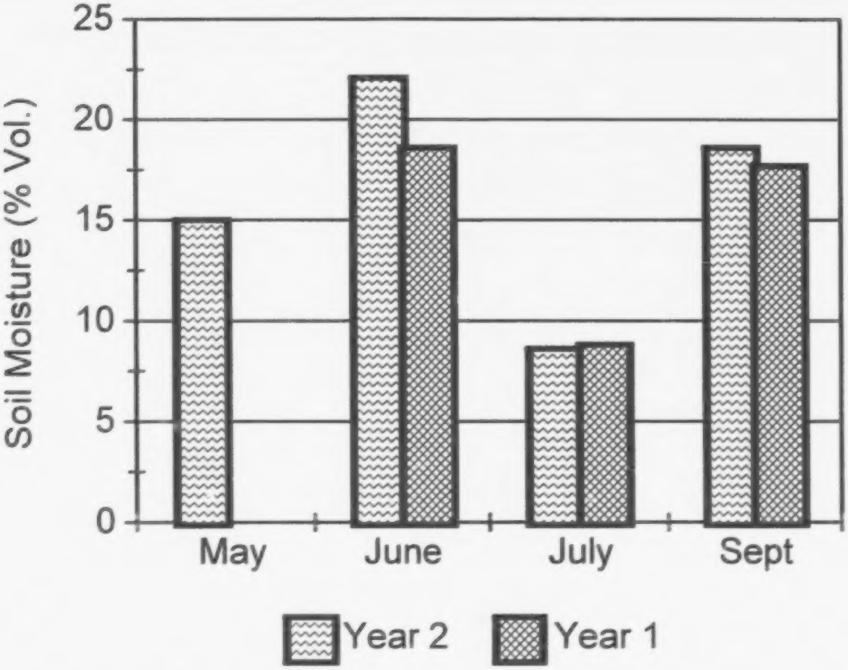

**Figure S2(03)-2:** Basal light availability (photons μmol $m^{-2}$ $s^{-1}$) for first year (seeded 2003) and second year of growth (seeded 2002).

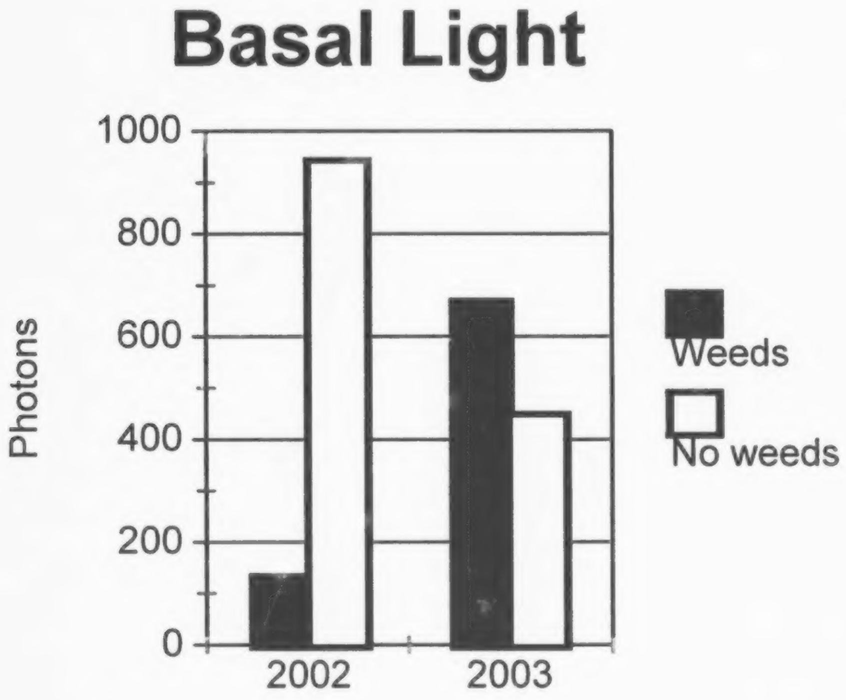

**Table S2(03)-1:** Average compositions, determined 30 September to 8 October 2003, as % for species found in plots started 2001. For abbreviations see Table S1(03)-1.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
| Mean | 12.4 | 1.7 | 1.4 | 0.1 | <0.1 | 0.5 | 20.8 | 8.1 | <0.1 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | WOATS | K | TG | KW | TPW |
| Mean | 1.5 | 0.2 | 4.7 | 0.4 | 0 | 2.8 | 0.6 | 0.1 | 1.5 |
| | | | | | | | | | |
| Species | RRPW | FBW | PPG | PPW | PF | PL | GF | FB | WT |
| Mean | 4.5 | 0.1 | 3.4 | 0 | 0.3 | 3.5 | <0.1 | <0.1 | 0.4 |
| | | | | | | | | | |
| Species | MD | GFOX | FW | BWW | TLS | BYG | RT | SOWT | PC |
| Mean | 0.1 | 0 | 2 | 0.1 | 0.1 | 0 | 0.2 | 0 | 0.1 |
| | | | | | | | | | |
| Species | MWG | MG | SW | CFB | PCF | TGMV | G | GB | FB |
| Mean | 6.5 | <0.1 | 0.3 | <0.1 | 0.3 | 0.1 | 0.2 | <0.1 | 0.1 |

**Table S2(03)-2:** Average compositions, determined 9 to 15 October 2003, as % for species found in plots started 2002. For abbreviations see Table S1(03)-1.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
| Mean | 0.8 | 0.5 | 0.1 | <0.1 | 0 | <0.1 | 1.6 | 0.3 | 0.1 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | LQ | K | MG | KW | FW |
| Mean | 0.3 | 0 | 0.3 | 0 | 2.8 | 1.1 | 0.2 | 1.2 | 4.1 |
| | | | | | | | | | |
| Species | MWG | FBW | PPG | PPW | SW | PL | RT | BWW | WT |
| Mean | 0.2 | 3.3 | 0.1 | 0.1 | 0.1 | 0.1 | 2.5 | 0.1 | 0.1 |
| | | | | | | | | | |
| Species | PCF | TGMV | G | GB | | | | | |
| Mean | <0.1 | <0.1 | 0 | 0 | | | | | |

**Table S2(03)-3:** Spring and fall seeding results for selected grasses with noted statistical ($\alpha = 0.05$) differences determined by Tukey's test for data collected in 2003 for experiments established in 2001 and 2002. Grasses are green needle grass (GNG), Little blue stem (LBS), awned wheatgrass (AWG), slender wheatgrass (SWG), western wheatgrass (WWG), northern wheatgrass (NWG) and needle and thread grass (NTG).

| Established 2001 | Fall Seeded | Spring Seeded |
|---|---|---|
| LBS | 0 | 0.2 |
| AWG | 3 | 6.3 |
| JG | 0 | 0.8 |
| GNG | 12.7 | 3.5 |
| Established 2002 | | |
| SWG | 3.2 | 0.1 |
| WWG | 1.5 | 0 |
| GNG | 0.5 | 0 |
| NWG | 1 | 0 |
| NTG | 0.6 | 0 |
| AWG | 0.6 | 0 |

**Table S2(03)-4:** Simpson's index of species richness for site established in 2001. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | |
|---|---|
| CV (%) | 14.6 |
| Mean | 0.77 |
| | |
| Mix | |
| Simple | 0.81 ab |
| Complex | 0.81 ab |
| Early Seral | 0.69 bc |
| Late Seral | 0.80 b |
| Early seral year 1 plus late seral year 1 | 0.82 ab |
| Late seral year 1 plus early seral year 1 | 0.70 bc |
| Early seral year 1 plus late seral year 2 | 0.86 a |
| Late seral year 1 plus early seral year 2 | 0.66 c |

**Table S2(03)-5:** Dry matter yields (g $m^{-2}$) for site established in 2001 and 2002. Values across rows with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | Weeds Present | No Weeds Present |
|---|---|---|
| Site established 2001 | | |
| Weeds Dry matter | 25.2 a | 0.4 b |
| Grass Dry Matter | 214.0 b | 429.6 a |
| Site Established 2002 | | |
| Weeds Dry matter | 126.8 a | 0.0 b |
| Grass Dry Matter | 0.0 b | 3.6 a |

**Table S2(03)-6:** Nutritional characteristics (organic matter (OM), organic matter digested (OMD), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP) and total phophorous (TP)) for material collected in 2002, one year of growth. Values with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | OM | OMD | ADF | NDF | CP | TP |
|---|---|---|---|---|---|---|
| CV (%) | 13.3 | 16.8 | 6.1 | 14.2 | 14.8 | 15.6 |
| MEAN | 88 | 54.8 | 56.7 | 37.1 | 11.6 | 0.18 |
| | | | | | | |
| Weeds (Pr>F) | 0.203 | <0.0001 | 0.003 | <0.0001 | <0.0001 | 0.0006 |
| Present | 90.1 a | 49.9 b | 57.9 a | 41.6 a | 9.5 b | 0.17 b |
| Removed | 86.0 b | 56.7 a | 55.6 b | 32.6 b | 14.1 a | 0.20 a |
| | | | | | | |
| Mix (Pr>F) | 0.0116 | 0.2115 | <0.0001 | 0.001 | 0.0077 | 0.1416 |
| Simple | 89.5 | 55.8 | 57.3 ab | 38.1ab | 11.5 ab | 0.18 |
| Complex | 89.7 | 56.8 | 56.1ab | 37.3 ab | 12.0 ab | 0.19 |
| Early Seral | 90 | 54.9 | 58.4 a | 38.7 a | 11.2 b | 0.18 |
| Late Seral | 85 | 53.6 | 55.1 b | 35.3 b | 12.4 a | 0.18 |
| | | | | | | |
| Time of Seeding (Pr>F) | 0.2305 | 0.9289 | 0.1303 | 0.2136 | 0.1147 | 0.0402 |
| Spring | 86.7 | 55.4 | 56.5 | 36.6 | 11.9 | 0.19 |
| Fall | 89.4 | 54.2 | 57 | 37.7 | 11.6 | 0.18 |

### *Large Pasture Plant Composition 2004*

Grazing outside the enclosure compared to no grazing within the enclosure resulted in decreased canopy cover in late August but increased the basal cover indicating an increase in basal plant material cover versus the lower basal cover for non grazed areas (Table LP(04)-01). There was more grass in quarter meter squared samples for ungrazed samples, as one would expect with cattle's removal of grass cover during foraging outside the enclosure. Grassy weeds were found in greater abundance outside the enclosures (but only a minor component) indicating a need for some level of disturbance, as provided by the cattle, for seedling establishment. The grazed pasture was more diverse than the ungrazed enclosures as noted by Simpsons index.

Complex mixture (17.3 %) had greater ($P < 0.05$) basal cover than the simple seed mix (12.4%). Litter covered 32.1% of the ground in simple mix pastures while the complex mix pastures had 24.0% litter cover ($P < 0.05$). Wheat grasses made up 97% of the composition of the simple mix but only 66% of the complex mix (Table LP (04)-2). Purple prairie clover, BG and LBS had the greatest increases. Blue grama, LBS and PPC may have increased due to decreased competition from the wheat grasses in the complex mix. The wheatgrasses made up a smaller proportion of the complex mix compared to the simple seed mix.

Examination of individual species indicates northern wheatgrass continues to dominate the ungrazed enclosures (Table LP(04)-2) but is greatly reduced from the 31.3% found in 2002 (Table LP(04)-3). The reduction in northern wheatgrass being due in part to increased presence of other species. Grazing reduced the amount of litter and moss formation ( Table LP(04)-2) indicating a disturbance may reduce the presence of moss. The reduction of litter resulted from removal of vegetative material as the cattle foraged. The reduction of litter and combined with grazing resulted also in increased bare ground.

Pastures with the higher stocking density had lower ($P < 0.05$) grassy weed composition (0.7 %) than pastures with the low stocking density (2.3%). Green needle grass made up a greater proportion ($P < 0.05$) of the high stocking rate pastures quarter metre square samples (2.0%) than the low stocking rate pastures (0.5%). Prairie sand reed also increased under high intensity grazing although not significantly (Table LP(04)-2).

Looking at the data over time (Table LP(04)-3) one first notes the plant communities are still evolving both under grazing and without grazing. For both grazed and ungrazed species richness, as indicated by the Simpson's Index, has increased but the grazed has a higher species richness. Trends for most species across years was similar although the rate of change differed between grazed and ungrazed. Slender wheatgrass differed between grazed and ungrazed. Under grazing in declined but increased without grazing suggesting an intolerance to grazing. The rhizomatous species such as little blue stem and western wheatgrass increased under both situations. Little blue stem was the only grass to increase during the dry year of 2003 likely due to its being a warm season grass. Weeds declined (represented by Kochia) in both situations. Under grazing they were gone by the second year. Open canopy has increased and bare ground has declined without grazing. Canopy cover has remained the similar in the grazed but more open than the ungrazed. Bare ground has increased, the largest increase (2002-2003) due to loss of straw resulting from its degradation.

Stocking density had no effect on the grass yields ($P > 0.05$). The simple mix had higher ($P = 0.04$) quarter metre square sample grass yields (17.6 g $m^{-2}$) than the complex mix (11.6 g $m^{-2}$). Insufficient weeds were present for sampling in 2004.

**Table LP(04)-1:** Canopy cover, basal cover, % grass composition (Grass), % purple prairie clover composition (PPC), % grassy weeds composition (GWeeds), % broadleaf weed composition (FWeeds) and Simpson's Index inside the grazing enclosure and in the pasture for 2004.

| **Parameter measured** | **Enclosure** | **Pasture** | **CV (%)** |
|---|---|---|---|
| | ------------------------------------------ % ------------------------------------------ | | |
| Canopy cover | 91.3* | 55.2 | 13.7 |
| Basal cover | 12.5 | 17.2* | 42.2 |
| Grass | 47.6* | 31.6 | 23.8 |
| PPC | 0.44 | 0.29 | 285.3 |
| GWeeds | 0.1 | 2.9* | 147.5 |
| FWeeds | 0.9 | 0.4 | 268.1 |
| Simpson's Index | 0.92 | 0.96* | 3.2 |

* - significant difference across rows ($P < 0.05$)

**Table LP(04)-2:** Seeded species, moss, litter and bareground contributions to quarter metre square composition sampling of large pasture studies for seed mixtures, inside or outside enclosures and stocking density for 2004.Values within the row of comparions followed by an * are statistically different at the 0.05 level as determined by the Tukey's test.

| | Comparisons | | | | | |
|---|---|---|---|---|---|---|
| **Species** | **Simple mix** | **Complex Mix** | **Inside Enclosure** | **Outside Enclosure** | **Low Stocking density (1.4 AU/ha)** | **High Stocking density (2.7 AU/ha)** |
| | ----- % composition ----- | | | | | |
| Western wheatgrass | 11.9 | 7.6 | 10.2 | 9.3 | 10 | 9.6 |
| Northern wheatgrass | 8.4 | 8.5 | 12.7 * | 4.2 | 9.6 | 7.3 |
| Green needle grass | 0.3 | 2.2* | 1.6 | 1 | 0.5 | 2.0 * |
| Awned wheatgrass | 3.9 | 2.9 | 3.5 | 3.3 | 3 | 3.7 |
| June grass | 0.2 | 0.3* | 0 | 0.5 | 0.3 | 0.2 |
| Slender wheatgrass | 9.9 | 4.6 | 8.6 | 5.8 | 8.2 | 6.2 |
| Purple prairie clover | 0.03 | 0.7 | 0.4 | 0.3 | 0.4 | 0.3 |
| Canadian wildrye | 0.01 | 0.01 | 0 | 0.02 | 0.012 | 0.006 |
| Little blue stem | 0.01 | 6.3* | 4.6 | 1.7 | 3.6 | 2.8 |
| Needle and thread grass | 0 | 0.2* | 0.03 | 0.1* | 0.05 | 0.12 |
| Blue grama | 0.3 | 1.9 * | 0.9 | 1.3 | 1.3 | 0.9 |
| Prairie sand reed | 0 | 0.4 | 0.4 | 0.1 | 0.1 | 0.3 |
| Saltbush | 0 | 0 | 0 | 0 | 0 | 0 |
| Winterfat | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | |
| Moss | 1.5 | 2.4 | 3.8 * | 0.1 | 1.8 | 2.1 |
| Litter | 32.1 * | 24 | 38.9 * | 17.2 | 27.8 | 28.4 |
| Bare ground | 0.7 | 1.8 | 0 | 44.9 * | 25.5 | 19.3 |

**Table LP(04)-3:** Key species, canopy cover, litter, moss and bare ground changes over time as per cent of cover in 1/4 $m^2$ samples.

| **Observed Factors** | **Enclosure** | | **Grazed** | | |
|---|---|---|---|---|---|
| | 2002 | 2004 | 2002 | 2003 | 2004 |
| | | | % | | |
| WWG | 2.7 | 10.2 | 5.3 | 3.1 | 9.3 |
| NWG | 31.3 | 12.7 | 8.9 | 5 | 4.2 |
| LBS | 0.7 | 4.6 | 1 | 1.9 | 1.7 |
| PPC | 0.1 | 0.4 | <0.1 | <0.1 | 0.3 |
| SWG | 3.1 | 8.6 | 7.2 | 6.3 | 5.8 |
| GNG | 0 | 1.6 | 0.4 | 0.4 | 1 |
| AWG | 7.5 | 3.5 | 5.7 | 5.3 | 3.3 |
| Kochia | 3.8 | 0 | 2.9 | 0.7 | 0 |
| Canopy | 73.1 | 91.3 | 60.1 | 60.9 | 55.2 |
| Litter | 1.6 | 38.9 | 1.5 | 24.1 | 17.2 |
| Bare ground | 8.1 | 0 | 6.6 | 39.1 | 44.9 |
| Simpsons Index | 0.86 | 0.94 | 0.93 | 0.71 | 0.96 |

### ***Small plot studies 2004***

### *S1 - Optimum seeding date (01615 & 02623)*

The year 2004 was a year with plenty of soil moisture as indicated by measurements obtained using time domain reflectrometry (TDR) (Table S1(04) - 1). No treatment differences were noted.

As one would expect no differences were noted for the top of the canopy but light readings taken at the ground level below the canopy indicate a more open canopy at the second site with younger plants (Table s1(04) - 2). At site 1 the June to October seedings had a more open canopy likely due to poorer establishment and thus thinner stands.

Plots at site 1 with 3rd year growth had a high degree of variability. Weeds were a minor component with Canadian flea bane and pepper grass being the dominant weed species (Table S1(04) - 4). Cool season grasses dominated the plots. A moss under-story had started to form and seedlings were starting to appear. The canopy had reached 90% of the1/4 $m^2$ samples.

Plots at site with 2nd year of growth continued to have a greater amount of weeds contributing to the plot compositions (Table S1(04) - 5) but the dominant weeds differed from site 1 with flixweed, red top and buck wheat dominating. The cool season grasses dominated the plots. The younger plant communities found at site 2 had a more open canopy. No moss under-story or seedlings were observed in these plots with younger plants.

The trends over time were similar for both sites with western wheatgrass, northern wheatgrass, slender wheatgrass, green needle grass and awned wheatgrass all increased while purple prairie clover declined (Table S(04) - 6). The lack of warm season grasses compared to the large pastures may be due in part to the harvesting date (in fall for small plots). In the pasture studies grazing provided a more open canopy and decreased the competitive advantage for cool season grasses.

The simple mix (35.6%) had more ($P < 0.05$) grass species than the complex mix (28.8%) for the younger seeding site (Site 2). The older site with 3rd year growth (site 1) had no differences due to seeding mix.

The date of seeding continued to have a detectable effect (Table S1(04) - 7) on basal cover, slender wheatgrass, green needle grass, seed grass in general and weeds for the site 1. The seeding dates in which the better establishment occurred (early spring, late fall) resulted in greater basal cover, greater seeded grasses and fewer weeds. Green needle grass continued to contribute more to the composition where it was seeded in late fall while slender wheatgrass contributed more to the composition in the plots in which it was seeded in early spring. For the 2nd site variation was higher and differences were not detectable except for awned wheatgrass which may have responded to the June/July rainfall in its establishment year.

The Simpson's index for 2004 for site 1 (Table S1(04) - 8) was similar to unweeded plots in 2003 (Table S1(03) - 6) whereas site 2 had an increase in its Simpson's index in 2004 (0.86) compared to 2003 (0.74). Jaccard's Index of Similarity showed a 64 % similarity between fall and late spring seeding, 57 % similarity between fall and early spring seeding and 66 % similarity between simple and complex mixes for 3rd year of growth for 2004. The greatest change from 2003 was the increase in similarity between seeding mixtures. This may be due to the loss of warm season grasses and fewer weeds. Jaccard's Index of Similarity for site 2 (2nd year of growth) in 2004 showed a 72 % similarity between fall and late spring seeding, 69 % similarity between fall and early spring seeding and 59 % similarity between simple and complex mixes. The seeding date showed a higher degree of similarity than the 3rd year of growth plots but were similar to results for 2003.

Dry matter yields (Table S1(04) - 9) for site 1 (3rd year of growth) had no differences due to seeding mix but early spring and late fall yielded the highest, not an unexpected result with greater establishment occurring at these dates. Weeds for site 1 had the opposite trend of seeded species and contributed more dry matter in complex seed mix plots. Yields were 1.9 times greater than those of 2002. For site 2 late fall plots had the highest seeded species yields whereas weeds showed no trends. The seeded species and weed yields were similar in 2004. The seeded species yields for 2004 (72 g $m-^2$ ) were greater than yields in 2003 ( 0.8g $m-^2$ ). Increases in yield would be expected as the plants increase in size and the weed component declines.

For both 2003 (Table S1(04) - 10) and 2004 (Table S1(04) - 11) no treatment effects were noted for OM, OMD, ADF, NDF, CP or P. Crude protein was higher in 2003 for seeded species compared to weeds. The seeded species were more digestible in 2004 than the weeds due to less fiber. Within in the literature it has been noted under hot dry conditions plants have lower fibre, greater digestibility and greater protein than under cool moist conditions. This is in part due the plants failure to grow thus containing less fibre.

**Table S1(04) - 1:** Average soil moisture (% volume) for 0 - 15 cm as determined by time domain reflectrometry for 2004 for sites two and three years of growth.

| **Second Year of Growth** | | **Third Year of Growth** | |
|---|---|---|---|
| Sampling Date | Soil Moisture (%) | Sampling Date | Soil Moisture (%) |
| 38478 | 19.6 | 38478 | 17.2 |
| 38511 | 28.7 | 38510 | 29.2 |
| 38544 | 21.8 | 38544 | 23.4 |
| 38569 | 15 | 38569 | 13.7 |

**Table S1(04) - 2:** Light readings taken 27 and 31 August from 11:30 am to 1:30 pm at the top and ground level of canopy with second and third year of growth. Measurements are in μmol $m^{-2}$ $s^{-1}$. Values in the columns with different letters following are statistically different at the 0.05 level as determined by the Tukey's test for ground level measurements. No statical differences were noted for the top of the canopy.

| | Second Year of Growth | Third Year of Growth |
|---|---|---|
| | ------------------------------ μmol $m^{-2}$ $s^{-1}$ | -------------------------- |
| Mean for top of Canopy | 1484.5 | 1504.6 |
| Seeding Date Means for Ground Level | | |
| April/May | 1087.8 | 449.6 b |
| May | 1102.8 | 474.9 b |
| June | 1039.3 | 778.6 a |
| June/July | 1055 | 859.8 a |
| October | 1006.4 | 885.8 a |
| October/November | 839.9 | 436.0 b |

**Table S1(04)-3:** Species abbreviations.

MWG = MISC. WHEATGRASS
WWG = W. WHEATGRASS
NWG = N. WHEATGRASS
BG = BLUE GRAMA
LBS = LITTLE BLUESTEM
SWG=SL. WHEATGRASS
FW=FLIXWEED
PPW = PROSTRATE PIGWEED
FB = FOXTAIL BARLEY
G-FOX = GREEN FOXTAIL
K=KOCHIA
TGMV=TWO GROOVED MILKVETCH
G=GAILLARDIA
MG = MISC. GRASS
GB= GOLDEN BEAN
PCF=PRAIRIE CONEFLOWER

PG = PEPPER GRASS
PPC = PURPLE PRAIRIE CLOVER
PSR = PRAIRIE SANDREED
LQ = LAMB'S QUARTER
NTG = NEEDLE-AND-THREAD
TG=TUMBLE GRASS
RT = RUSSIAN THISTLE
GNG = GREEN NEEDLE GRASS

BYG = BARN YARD GRASS
KW=KNOTWEED
PF-PYGMY FLOWER
PL=PURSLANE

LW=LOCOWEED
BBW = BUCK WHEAT
KW = KNOTWEED
DBS=DOTTED BLAZING STAR

TLS=THYME-LEAVED SPURGE
CWR = CANADIAN WILD RYE
AWG = AWNED WHEATGRASS
W-OATS = WILD OATS
TPW = TUMBLE PIGWEED
RRPW = RED ROOT PIGWEED
GF=SPEAR LEAVED GOOSEFOOT
WT=WILD TOMATO

Md=MUSTARD
PRLE = PRICKLY LETTUCE
FBW=FIELD BINDWEED
BWW=BIENNIAL WORM WOOD

SW=STINKWEED
RT = RED TOP
CFB = CANADA FLEABANE
CWG=CRESTED WHEATGRASS

**Table S1(04)-4:** Average compositions, determined 8 to 17 September 2004, as % for species found in plots seeded fall 2001 and spring 2002 (3rd year of growth).

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
| Mean | 12 | 8.7 | 0.1 | 0.01 | 0 | 0.01 | 10.1 | 12.2 | 0 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | FW | K | TG | KW | TPW |
| Mean | 0.3 | 0.2 | 10.1 | 0.9 | 2.3 | 0.5 | 1.6 | 0.03 | 1.5 |
| | | | | | | | | | |
| Species | PPG | FB | CFB | PC | Moss | | | | |
| Mean | 3.3 | 2 | 6.2 | 1.2 | 1.3 | | | | |
| | | | | | | | | | |
| Other | Canopy | Basal | Litter | Grassy Weeds | Forb Weeds | Seeded Grass | Seedlings | | |
| Mean | 90.2 | 14 | 13.3 | 4.8 | 13.7 | 57.1 | 2.4 | | |

**Table S1(04)-5:** Average compositions, determined 30 September to 5 October 2004, as % for species found in plots seeded fall 2002 and spring 2003 (2nd year of growth).

| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.9 | 8.7 | 0 | 0.01 | 0 | 0 | 6.4 | 7.1 | 0 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | FW | RT | BBW | PPG | |
| Mean | 1.1 | 0.2 | 6 | 0 | 23.9 | 2.9 | 4.3 | 1.2 | |
| | | | | | | | | | |
| Other | Canopy | Basal | Litter | Seedlings | Grassy Weeds | Forb Weeds | Seeded Grass | | |
| Mean | 72.6 | 7.4 | 7.5 | 0.4 | 0.01 | 33.5 | 32.2 | | |

**Table S1(04)-6:** Key species changes over time.

| **Observed Factors** | **Site 1** | | | **Site 2** | |
|---|---|---|---|---|---|
| | 2002 | 2003 | 2004 | 2003 | 2004 |
| WWG | 5.3 | 7.7 | 12 | 0.3 | 0.9 |
| NWG | 3.5 | 1.2 | 8.7 | 0.1 | 8.7 |
| LBS | 0.7 | 0.1 | 0.01 | 0 | 0.01 |
| PPC | 0.1 | <0.1 | 0 | <0.1 | 0 |
| SWG | 3.9 | 1.7 | 10.1 | 0.6 | 6.4 |
| GNG | 5.2 | 6.3 | 12.2 | 0.2 | 7.1 |
| AWG | 3.7 | 8.3 | 10.1 | 0.1 | 6 |
| Kochia | 20.5 | 10.3 | 0.5 | 0 | 0 |

**Table S1(04)-7:** Average compositions, determined 13 to 16 September 2004, as % for species found in plots with 3rd and 2nd year of growth with a significant effect due to date of seeding. Values in rows with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | **Date of Seeding** | | | | | |
|---|---|---|---|---|---|---|
| **3rd Year of Growth** | April/May | May | June | June/July | October | October/Nov. |
| Basal Cover | 16.9 ab | 20.0 a | 9.4 c | 11.9 b | 9.4 c | 16.3 ab |
| **Species** | | | | | | |
| SWG | 17.9 a | 14.1 a | 9.4 b | 3.5 b | 10.6 a | 5.6 b |
| GNG | 9.0 b | 5.6 b | 10.9 ab | 7.8 b | 11.9 ab | 28.1 a |
| FW | 0.4 b | 0.0 b | 4.3 a | 4.8 a | 4.6 a | 0.1 b |
| K | 0.0 b | 0.1 ab | 0.2 ab | 1.9 a | 0.3 ab | 0.2 ab |
| PPG | 0.6 b | 0.4 b | 3.5 ab | 5.6 ab | 8.6 a | 1.0 b |
| BBW | 0.1 b | 0.1 b | 0.5 b | 0.9 b | 2.6 a | 0.1 b |
| Grassy Weeds | 0.0 b | 2.3 b | 11.4 a | 12.0 a | 2.0 b | 0.9 b |
| Forb Weeds | 2.6 b | 1.0 b | 17.4 ab | 29.7 a | 26.0 a | 5.7 b |
| Seeded Grass | 74.0 a | 74.6 a | 41.2 b | 36.2 b | 43.9 b | 72.1 a |
| **2nd Year of Growth** | | | | | | |
| AWG | 6.3 ab | 0.3 b | 12.1 a | 7.9 ab | 3.1 b | 6.3 ab |

**Table S1(04)-8:** Simpson's Index and Jaccard's Index of Similarity for 3rd and 2nd year of growth in 2004. Numbers in parentheses are the standard errors.

| Index | 3rd Year of Growth | 2nd Year of Growth |
|---|---|---|
| **Simpson's** | 0.81 (15.5) | 0.86 (10.4) |
| **Jaccard's** | | |
| Fall vs Late Spring | 64.1 (12.6) | 71.7 (7.5) |
| Fall vs Early spring seeding | 56.9 (4.0) | 69.2 (6.8) |
| Simple vs Complex Seed Mix | 65.9 (13.8) | 59.3 (2.1) |

**Table S1(04)-9:** Dry matter yields for seeded species and weeds for 2004 for sites with 3rd and 2nd year of growth. Values in columns with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | **3rd Year of Growth** | | **2nd Year of Growth** | |
|---|---|---|---|---|
| **Factor** | Seeded Species | Weeds | Seeded Species | Weeds |
| | ---------- g $m^{-2}$ ---------- | | | |
| **Seed Mix** | | | | |
| Simple | 368 | 20.25 b | 83.3 | 56.7 b |
| Complex | 373.1 | 47.3 a | 61.3 | 81.4 a |
| **Seeding Date** | | | | |
| April/May | 551.3 a | 1.0 b | 70.4 ab | 63.5 |
| May | 583.1 a | 0.2 b | 38.3 b | 84.3 |
| June | 247.9 b | 27.2 b | 61.3 ab | 69.4 |
| June/July | 145.3 b | 109.1 a | 61.7 ab | 80.6 |
| October | 137.3 b | 51.6 ab | 99.3 ab | 68.1 |
| October/November | 558.3 a | 13.5 b | 109.1 a | 48.2 |
| **Mean** | 370.5 | 33.8 | 72.3 | 69 |
| **CV (%)** | 37.3 | 132 | 32 | 56.3 |

**Table S1(04)-10:** Means for organic matter (OM), organic matter digestibilities (OMD), acid detergent fibre (ADF), crude protein (CP) and total phosphorous (P) for weed and seeded species for 1st year of growth in 2003. No statistically significant ($\alpha = 0.05$) values.

| Nutritional Component | Seeded Species | Weeds |
|---|---|---|
| | ---------- % ---------- | |
| OM | na[1] | 87.1 |
| OMD | na | 52.7 |
| ADF | na | 33.9 |
| NDF | na | 50.1 |
| CP | 11.2 | 9.4 |
| P | 0.2 | 0.7 |

[1] - insufficient sample available for analyses.

**Table S1(04)-11:** Means for organic matter (OM), organic matter digestibilities (OMD), acid detergent fibre (ADF), crude protein (CP) and total phosphorous (P) for weed and seeded species for 2nd and 3rd year of growth in 2004. No statistically significant ($\alpha = 0.05$) values.

| | 3rd Year of Growth | | | | 2nd Year of Growth | | | |
|---|---|---|---|---|---|---|---|---|
| **Nutritional Component** | Seeded species | CV | Weeds | CV | Seeded species | CV | Weeds | CV |
| | % | | | | | | | |
| OM | 91.4 | 0.7 | na[1] | ----- | 88.3 | 1.5 | 95.6 | 1.4 |
| OMD | 44.1 | 6.6 | na | ----- | 52.5 | 7.2 | 32.4 | 13.5 |
| ADF | 39.2 | 6 | 45.7 | 15.5 | 33.6 | 10.7 | 57.1 | 9 |
| NDF | 67.4 | 2.3 | 58.6 | 4.9 | 57.4 | 7.3 | 70.2 | 8.5 |
| CP | 4.1 | 37.3 | 5.8 | 7.6 | 9.5 | 21.8 | 5.5 | 24.8 |
| P | 0.12 | 11.4 | 0.2 | 13.9 | 0.2 | 17.1 | 0.13 | 26.2 |

[1] - insufficient sample available for analyses.

*S2 - Seral stages study (01614 & 02622)*

The year 2004 was a year with plenty of soil moisture as indicated by measurements obtained using TDR (Table S2(04) - 1). No treatment differences were noted.

As one would expect no differences were noted for the top of the canopy but light readings taken at the ground level below the canopy indicate a more open canopy at the second site with younger plants (Table S2(04) - 2). At site 2 spring seedings had a more open canopy than fall seedings likely due to poorer establishment and thus thinner stands.

Plots at site 1 with 3rd year growth had a high degree of variability. Weeds were a minor component with Canadian flea bane and pepper grass being the dominant weed species (Table S1(04) - 3). Cool season grasses dominated the plots. Purple prairie clover, winterfat prairie cone flower, golden bean and gallardia were present. A moss under-story had started to form and seedlings were starting to appear. The canopy has reached 97% of the1/4 $m^2$ samples. The species richness decreased from 0.8 in 2003 to 0.7 in 2004. The decrease could be possibly due to loss of the warm season grasses and fewer weeds.

Plots at site with 2nd year of growth continued to have a larger amount of weeds the composition (Table S1(04) - 4) but the dominant weeds differed with kochia, flixweed, pepper grass and red top dominating. The cool season grasses dominated the plots. The younger plant communities found at site 2 had a more open canopy. Some moss under-story and seedlings were observed in these plots of younger plants but considerable less than in site 1. For site 2 the species richness remained the approximately the same as in 2003.

Looking at trends across years, most of the cool season grasses increased from 2002 to 2003 at both sites (Table S2(04) - 5). Purple prairie clover increased during this period as well but the only warm season grass, little blue stem decreased as did the weeds represented by kochia. Similar trends are noted for most of the noted seeded species at site for the period 2003 to 2004, except awned wheatgrass which declined. Kochia increased from 2003 to 2004.

Seeding date factor for site 1 was still evident for a number of species (Table S2(04) - 6). Plots seeded in spring continued to have higher amounts of northern wheatgrass and purple prairie clover while fall seeded plots had higher amounts of green needle grass and weeds. The higher weed composition in fall seeded plots was likely due to thinner stands. The weed composition, even in the fall seeded plots was relatively low. Seeding date factor for site 2 was very different than site 1 (Table S2(04) - 8). The seeded species for which date of seeding was significant all contributed more to the composition when seeded in fall. The weeds dominated the spring seeded plots. This difference likely reflects the difference in weather conditions with spring 2003 being a very dry spring as opposed to the more normal precipitation in spring 2002. Fall seeding may be something to consider if climate change trends for the future hold with drier conditions being suggested.

The seeding mix differences for site 1 were detectable after 3 years for 5 cool season grasses and a legume (Table S2(04) - 7). Four of the 5 grasses were seeded as late seral species but green needle grass, needle and thread grass and northern wheatgrass were present in greater amounts in the late seral mix. Western wheatgrass was present in greater amounts in the simple, complex and late seral seedings following the early seral seeding suggesting an ability to contribute more shortly after seeding under a fall harvest regime. Slender wheatgrass was present in greater amounts when seeded as a early seral species alone or following a late seral seeding. Northern wheatgrass may be fading in the simple mix where a larger proportion of the mix was other wheatgrasses. Data from the large pastures indicated a northern wheatgrass made up a large proportion early in succession but contributed less as the swards aged. Slender wheatgrass is known as a heavy seed producer and is likely the species contributing to the seedlings found in the early seral seeding. The complex mix had the greater species richness with rest of the mixes being similar. This may again be due to low proportion of warm season grasses being present in the other mixtures compared to the complex.

The seeding mixture effect was detectable in only 5 species with 2 being late seral grasses while the other 3 were listed as early seral (Table S2(04) - 9). The late seral species, northern wheatgrass and green needle grass did not contribute to the early seral seeding and marginally late seral with early seral a year later. The latter may be a result of undesirable conditions for seedling growth the first year (spring 2003). The same may be true for slender wheatgrass and winterfat. Awned wheatgrass contributed the most in the simple mix. No differences wee detected for species richness.

Jaccard's index of similarity indicated no differences in similarity between seeding mixtures (Table S2(04) - 10). For site 1 the mean Jaccard's index of similarity was 56.1% with a standard error of 3.5 and site 2 had a Jaccard's index of similarity of 51.5% with a standard error of 6.2. Compared to values calculated in 2003 (Page 70) both sites are moving towards greater similarity with decreasing variation. This may be due to loss of species such as warm season grasses and weeds due the competitive advantage given to the more aggressive cool season wheatgrass species under a single fall harvest.

There was no treatment effect indicated for dry matter yields for site 1 which had a mean seeded species dry matter yield of 604 g m $^{-2}$ (Table S2(04) - 11), a 3 fold increase in yield over 2003. Weeds for site 1 produced only 2.5 g m $^{-2}$. This increase in grass dry matter yield was likely due to better environmental conditions for production and older plants. Site 2 weed dry matter yields were similar to those of 2003 with a mean of 212 g m$^{-2}$ but the seeded species dry matter yield increased 30 times to give 111.4 g m$^{-2}$. There was a significant 8.7 times increase in seeded species yields for fall seeded plots versus spring seeded plants in 2004. The difference in seeding date yields was likely due to failure of seeded species to establish resulting from poor establishment conditions in 2003. The increase in yield from 2003 to 2004 would be in part to improved growth conditions and older plants.

In 2003, there were no differences due to treatment factors detectable for nutritional components for either site (Table S2(04) - 12). Site 2 plants had less fibre, greater digestibility greater crude protein and greater P than site 1 due to younger plants. In 2004, this difference in sites is still evident likely due to the same reason. In 2003 plants from both sites have less fibre, greater digestibility, and greater crude protein than plants in 2004. These differences between years may be due to increased age of the plants and a difference in the growing environment. Within in the literature it has been noted under hot dry conditions plants have lower fibre, greater digestibility and greater protein than under cool moist conditions. This is in part due the plants failure to grow thus containing less fibre.

**Table S2(04) - 1:** Average soil moisture (% volume) for 0 - 15 cm as determined by time domain reflectrometry for 2004 for sites two and three years of growth.

| **Second Year of Growth** | | **Third Year of Growth** | |
|---|---|---|---|
| Sampling Date | Soil Moisture (%) | Sampling Date | Soil Moisture (%) |
| 38478 | 17.8 | 38478 | 16.6 |
| 38510 | 27.1 | 38510 | 29.5 |
| 38544 | 20.8 | 38544 | 24.6 |
| 38569 | 15.1 | 38569 | 15.8 |

**Table S2(04) - 2:** Light readings taken 27 and 31 August from 11:30 am to 1:30 pm at the top and ground level of canopy with second and third year of growth. Measurements are in µmol $m^{-2}$ $s^{-1}$. Values in the columns with different letters following are statistically different at the 0.05 level as determined by the Tukey's test for ground level measurements. Numbers in parentheses are coefficient of variance (%).

| | Second Year of Growth | Third Year of Growth |
|---|---|---|
| | ------------------------------ µmol $m^{-2}$ $s^{-1}$ | -------------------------- |
| Mean for top of Canopy | 1432.8 (2.8) | 1601.4 (4.9) |
| Seeding Date Effect for Ground Level | -37.9 | -44 |
| Spring | 537.9 a | 479.4 |
| Fall | 344.6 b | 447.5 |

**Table S2(04)-3:** Average compositions, determined 23 - 29 September 2004, as % for species found in plots started 2001. For abbreviations see Table S1(04)-3.

| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 14.8 | 14.7 | 0.8 | 0.1 | 0.3 | 0.2 | 22.1 | 11.3 | 0.4 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | BW | K | PPG | GB | PCF |
| Mean | 1.1 | 0.9 | 3.4 | 0.8 | 0.1 | 0.1 | 1.6 | 0.2 | 0.7 |
| | | | | | | | | | |
| Species | MOSS | G | FW | MF | PF | CFB | | | SIMP-SONS INDEX |
| Mean | 2.1 | 0.7 | 0.6 | 0.3 | 0.7 | 0.4 | | | 0.7 |
| | | | | | | | | | |
| Others | Seedling | Grass weeds | Forb weeds | Grass | Forbs | Legumes | Canopy cover | Basal ground cover | Litter |
| Mean | 7 | 0.1 | 4.6 | 50.5 | 1.4 | 0.4 | 97.2 | 17.5 | 14.8 |

**Table S2(04)-4:** Average compositions, determined 5 to 26 October 2004, as % for species found in plots started 2002. For abbreviations see Table S1(04)-3.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | WWG | NWG | BG | LBS | PPC | PSR | SWG | GNG | WF |
| Mean | 1.1 | 7.5 | 0.1 | 0 | 0.01 | 0 | 9.4 | 2.8 | 0.4 |
| | | | | | | | | | |
| Species | NTG | CWR | AWG | JG | FB | K | KW | BW | FW |
| Mean | 0.9 | 0 | 0 | 0.4 | 0.2 | 27.8 | 0.7 | 0.8 | 5.1 |
| | | | | | | | | | |
| Species | MOSS | PRLE | PPG | RT | Seedling | Grass | Forb weeds | Grass weeds | Forbs |
| Mean | 0.1 | 0.5 | 1.6 | 2 | 0.1 | 25.5 | 38.9 | 0.1 | 1.4 |
| | | | | | | | | | |
| Others | Legumes | Canopy cover | Basal ground cover | Litter | Simp-sons Index | | | | |
| Mean | 0.1 | 74 | 9.3 | 9.5 | 0.8 | | | | |

**Table S2(04)-5:** Key species changes over time.

| **Observed Factors** | **Site 1** | | | **Site 2** | |
|---|---|---|---|---|---|
| | 2002 | 2003 | 2004 | 2003 | 2004 |
| WWG | 4.1 | 12.4 | 14.8 | 0.8 | 1.1 |
| NWG | 2.4 | 1.7 | 14.7 | 0.5 | 7.5 |
| LBS | 0.2 | 0.1 | 0.1 | <0.1 | 0 |
| PPC | <0.1 | <0.1 | 0.3 | 0 | 0.01 |
| SWG | 11.6 | 20.8 | 22.1 | 1.6 | 9.4 |
| GNG | 3.7 | 8.1 | 11.3 | 0.3 | 2.8 |
| AWG | 2.4 | 4.7 | 3.4 | 0.3 | 0 |
| Kochia | 23.4 | 2.8 | 0.1 | 1.1 | 27.8 |

**Table S2(04)-6:** Average compositions for date of seeding factor, determined 23 - 29 September 2004, as % for species found in plots started 2001. Values within rows with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | **Seeding Date** | | |
|---|---|---|---|
| **Species** | Spring | Fall | **CV (%)** |
| | --------------------------- % | ---------------------- | |
| Northern wheatgrass | 20.0 a | 9.3 b | 80.4 |
| Purple prairie clover | 0.50 a | 0.02 b | 304.1 |
| Green Needle Grass | 3.8 b | 18.9 a | 102.5 |
| Forb weeds | 2.7 b | 6.4 a | 114 |
| Legumes | 0.8 a | 0.1 b | 282.9 |
| Pepper grass | 0.9 b | 2.2 a | 223..1 |

**Table S2(04)-7:** Average compositions for seeding mix, determined 23 - 29 September 2004, as % for species found in plots started 2001. Values within columns with different letters following are statistically different at the 0.05 level as determined by the Tukey's test. Abbreviations as in Table S1(04)-3.

| Seeding Mixture | WWG | NWG | PPC | SWG | GNG | NTG | SEED-LING | SIMP-SONS | GRASS | FORBS |
|---|---|---|---|---|---|---|---|---|---|---|
| Simple | 33.1 a | 13.8 bc | 0.1 ab | 9.4 b | 15.6 ab | 0.0 b | 2.7 b | 0.76 ab | 71.9ab | 0.0 b |
| Complex | 20.0 ab | 16.0 abc | 0.1 ab | 11.2 b | 12.3 ab | 0.7 ab | 3.1 b | 0.83 a | 62.8 b | 6.4 a |
| Early Seral (E S) | 0.0 c | 0.0 c | 1.3 a | 50.6 a | 0.0 b | 0.0 b | 22.5 a | 0.64 b | 10.0 c | 0.6 ab |
| Late Seral (L S) | 14.4 bc | 27.6 ab | 0.0 b | 0.7 b | 19.4 a | 3.1 ab | 6.9 b | 0.75 ab | 72.6 ab | 0.0 b |
| E S + LS 1YR LATER | 28.1 ab | 34.4 a | 0.1 ab | 0.9 b | 16.0 ab | 3.8 a | 2.7 b | 0.72 ab | 86.5 a | 0.1 ab |
| LS + ES 1YR LATER | 0.0 c | 0.0 c | 0.1 ab | 56.3 a | 0.0 b | 0.0 b | 6.3 b | 0.62 b | 11.3 c | 1.3 ab |
| E S + LS 2YR LATER | 21.2 ab | 25.6 ab | 0.1 ab | 0.0 b | 26.9 a | 1.5 ab | 3.3 b | 0.67 ab | 77.8 ab | 0.0 b |
| LS + ES 2YR LATER | 1.3 c | 0.0 c | 0.4 ab | 47.8 a | 0.0 b | 0.0 b | 9.0 b | 0.67 ab | 10.8 b | 2.6 ab |
| **CV (%)** | 71.3 | 80.4 | 304.1 | 52 | 102.5 | 174.7 | 107.9 | 16.4 | 27.5 | 291.7 |

**Table S2(04)-8:** Average compositions for date of seeding factor, determined 5 to 26 October 2004, as % for species found in plots started 2002. Values within rows with different letters following are statistically different at the 0.05 level as determined by the Tukey's test. For abbreviations see Table S1(04)-3.

|  | **Seeding Date** |  |  |
|---|---|---|---|
| **Species** | Spring | Fall | **CV (%)** |
|  | ---------------------------- % | ---------------------- |  |
| Canopy cover | 68.3 b | 79.7 a | 8.1 |
| Basal ground cover | 6.7 b | 11.9 a | 18.6 |
| WWG | 0.3 b | 1.9 a | 98.5 |
| NWG | 4.3 b | 10.6 a | 41.8 |
| SWG | 5.2 b | 13.7 a | 50.4 |
| GNG | 1.4 b | 14.1 a | 67.8 |
| NTG | 0.1 b | 1.8 a | 111.8 |
| AWG | 1.3 b | 5.5 a | 79.2 |
| JG | 0.0 b | 0.8 a | 120.2 |
| Forb Weeds | 45.6 a | 32.2 b | 19.5 |
| Grass | 16.7 b | 38.4 a | 22.2 |

**Table S2(04)-9:** Average compositions for seeding mixture factor, determined 5 to 26 October 2004, as % for species found in plots started 2002. Values within rows with different letters following are statistically different at the 0.05 level as determined by the Tukey's test. For abbreviations see Table S1(04)-3.

| **Seeding Mixture** | **NWG** | **SWG** | **GNG** | **WF** | **AWG** |
|---|---|---|---|---|---|
| Simple | 7.8 a | 5.6 bc | 7.5 a | 0.0 b | 14.4 a |
| Complex | 131.1 a | 5.1 bc | 4.1 a | 0.0 b | 3.8 b |
| Early Seral (ES) | 0.0 b | 17.1 ab | 0.0 b | 0.0 b | 2.9 b |
| Late Seral (LS) | 10.7 a | 2.8 bc | 3.0 a | 0.0 b | 0.3 b |
| ES + LS 1 YR LATER | 16.9 a | 0.0 b | 4.2 a | 0.0 b | 0.0 b |
| LS + ES 1 YR LATER | 0.5 b | 25.0 a | 0.3 b | 3.2 a | 2.5 b |
| **CV** (%) | 74.6 | 90.1 | 121 | 402 | 141.4 |

**Table S1(04)-10:** Jaccard's Index of Similarity for both sites in 2004. No differences ($P > 0.05$) found using Tukey's test.

| Comparison | Site 2 started in 2002 | Site 1 started in 2001 |
|---|---|---|
| Simple vs Complex | 61.4 | 59.8 |
| Simple vs ES + LS 1YR LATER | 41.1 | 48.5 |
| Simple vs ES + LS 2YR LATER | 43.3 | 46.2 |
| Simple vs ES + LS 3 YR LATER | ------ | 55.7 |
| Simple vs LS + ES 1YR LATER | 47.1 | 63.2 |
| Simple vs LS + ES 2YR LATER | 58.9 | 60.1 |
| Simple vs LS + ES 3YR LATER | ------ | 55.7 |
| Spring vs Fall | 57.01 | 59.8 |
| **Standard Error** | 6.2 | 3.5 |
| **Mean** | 51.5 | 56.1 |

**Table S2(04)-11:** Dry matter yields for seeded species and weeds for 2004 for both sites. Values within columns with different letters following are statistically different at the 0.05 level as determined by the Tukey's test.

| | **Site 1 started in 2001** | | **Site 2 started in 2002** | |
|---|---|---|---|---|
| **Factor** | Seeded Species | Weeds | Seeded Species | Weeds |
| | ---------- g $m^{-2}$ ---------- | | | |
| **Means** | 604.2 | 2.5 | 111.4 | 212.2 |
| **CV (%)** | 30.6 | 310 | 119.1 | 75.2 |
| **Seeding Date** | | | | |
| Spring | 608.2 | 1.1 | 23.0 b | 246.4 |
| Fall | 600.6 | 3.9 | 199.7 a | 177.9 |

**Table S2(04)-12:** Means for organic matter (OM), organic matter digestibilities (OMD), acid detergent fibre (ADF), crude protein (CP) and total phosphorous (P) for weed and seeded species for both sites in 2003. No statistically significant ($\alpha = 0.05$) values.

| | **Site 1 started in 2001** | | | | **Site 2 started in 2002** | | | |
|---|---|---|---|---|---|---|---|---|
| **Nutritional Component** | Seeded species | CV | Weeds | CV | Seeded species | CV | Weeds | CV |
| | ---------------------------------------- | | | % | ---------------------------------------- | | | |
| OM | 91.3 | 1.8 | 92.7 | 1.5 | 86.8 | 4.2 | 91 | 3.1 |
| OMD | 46.6 | 8 | 54.5 | 7.3 | 64 | 10.4 | 52.3 | 17.2 |
| ADF | 39.8 | 7.1 | 42.2 | 16.2 | 29.6 | 13.6 | 42.5 | 17.2 |
| NDF | na[1] | ----- | 55.3 | 6.2 | na | ----- | 55.3 | 13.2 |
| CP | 5.1 | 30.1 | 8.7 | 33.4 | 9.4 | 27.4 | 8.6 | 30.1 |
| P | 0.08 | 33 | 0.13 | 39.4 | 0.09 | 37.4 | 0.12 | 28.4 |

[1] - insufficient sample available for analyses.

**Table S2(04)-13:** Means for organic matter (OM), organic matter digestibilities (OMD), acid detergent fibre (ADF), crude protein (CP) and total phosphorous (P) for weed and seeded species for both sites in 2004. No statistically significant (α = 0.05) values.

| | **Site 1 started in 2001** | | **Site 2 started in 2002** | |
|---|---|---|---|---|
| **Nutritional Component** | Seeded species | CV | Seeded species | CV |
| | ---------- % | ---------- | ---------- | ---------- |
| OM | 92.8 | 1.6 | 89.8 | 2.2 |
| OMD | 43 | 8.2 | 49 | 9.9 |
| ADF | 42.2 | 8.3 | 34.9 | 24.8 |
| NDF | 70.5 | 6.7 | 62.1 | 9.3 |
| CP | 3.9 | 24.3 | 7.1 | 25.2 |
| P | 0.1 | 27.9 | 0.14 | 26.2 |

## Economic analysis of re-establishment of a simple and complex mixed native grassland

### *Introduction*

Recent incentives, such as the Greencover Canada Land Conversion and the Canada Environmental Farm Plan programs, have stimulated an increasing number of producers in western Canada to seed marginal cropland to permanent cover and to make environmental sustainability a key component of their agricultural practice (AAFC 2005). Increase forage resources are needed in Western Canada to meet the current and future growth of the Canadian livestock industry (AAFC, PFRA and Rural Secretariat 1999). Saskatchewan's cow herd alone has increased by 40% over the past 10 years, with the total number of cows now approaching 1.5 million head. Tame grasses such as crested wheatgrass (*Agropyron cristatum* L.), meadow bromegrass (*Bromus riparius* Schrad.) and Russian wildrye (*Elymus juncea* Fisch.) are well-adapted to the semiarid region of southwestern Saskatchewan; they are relatively easy to establish and produce high dry matter yields (DMY) (Lawrence and Ratzlaff 1985). Past research on these grasses has focused on their ability to provide early spring grazing and for their value in extending the grazing season (Lawrence and Ratzlaff 1989). Alfalfa (*Mediago sativa L.*) is a legume that is often grown in combination with these tame grasses to further enhance forage yields and pasture productivity (Kopp et al. 2003).

In the past, tame grasses have produced higher DMY and seed yield than native species, suggesting that tame species are superior for adoption by area producers (Lawerence and Ratzlaff 1989). However, with the recent development of ecovars, native cultivars have become more economically attractive due to reduced seed costs and lower risk of establishment (Iwaasa and Schellenberg 2005). As seed supplies of native species continue to increase, the price for seed will continue to decline. For example, the price of needle-and-thread grass has dropped from $230 to $99 per kg from 2000 to 2002 (Peter Novak 2005 personal communication). The Greencover program recognizes the higher cost of seeding natives by providing $247 ha$^{-1}$ in financial assistance for establishing native species versus $111 ha$^{-1}$ for tame forages (AAFC 2005). The drop in seed price is also making native species a more viable option for producers looking to increase biodiversity as a means to combat invasion by weeds.

There are still other economic and social benefits from planting native species such as carbon sequestration, in which natives may have the ability to sequester higher rates of soil carbon compared to tame species (Christian and Wilson 1999). As a result of Canada's international commitments to the Kyoto Accord and with the establishment of a carbon trading market, opportunities may develop for producers to capture additional returns from the higher rates of soil carbon sequestration by natives. Use of native species also permit producers to extend the grazing season into the fall period, offering the potential to reduce overall costs for harvested forage and feed supplements. Natives hold their nutritional quality into the summer and winter better than tame grasses which typically mature and loose quality in early summer. Thus, providing an additional economic incentive for producers to plant native versus tame forage species.

### *Species descriptions, production, longevity and seeding rates*

Although a number of different forage species could be grown in the southwest part of Saskatchewan and following forages were selected since they are well-suitable and adapted to this region and are recommended in the Saskatchewan Forage Crop Production Guide 2005.

Crested wheatgrass (CWG) is an extremely hardy, long lived, and drought tolerant perennial bunchgrass. It has a widespread, deep penetrating root system making it ideal for stabilizing soil and preventing erosion. It has high resistance to cold, drought, and grazing (Reynolds and Springfield 1953). Crested wheatgrass yields are initially high after establishment, but drop sharply after the fourth or fifth year. A long-term production level or yield plateau then emerges which is dependant upon precipitation (Looman and Heinrichs 1973). Smoliak et al. (1967) reported that older CWG pastures still consistently produced higher DMY than native range, despite heavy grazing. While CWG is best suited to spring grazing, it is also suitable for fall grazing. Crested wheatgrass is easy to establish and it produces more forage yield than native species or Russian Wildrye (Smoliak et al. 1981). The seeding rate recommended by Saskatchewan Agriculture and Food (SAF) (2005) is 5.0 kg $ha^{-1}$. Even though the forage quality declines throughout the growing season (Smoliak and Bezeau 1967), the many advantages of CWG have kept this tame grass popular over the years.

Meadow Bromegrass (MBr) another bunchgrass is characterized as having good regrowth after grazing; making it good for season long grazing assuming moisture is available. Meadow bromegrass is normally used only for grazing due to its low basal leaves which make it difficult for haying. Gains of 0.94 kg $d^{-1}$ have been reported for British x Continential beef cows gazing MBr in the Black soil zone (Thompson et al. 2003). The first year of production is moderate due to stands not being fully established and by the fourth year, yields begin to decline due to the stands becoming sod bound (Westover et al. 1932). A seeding rate of 13.5 kg $ha^{-1}$ is recommended by SAF (2005).

Russian Wildrye (RWR) is a long-lived, drought tolerant, hardy pasture grass that provides excellent gains on pasture. Russian wildrye is adapted for early spring and fall use but can be used throughout the grazing season. This cool-season bunchgrass has good regrowth with high digestibility and a fairly constant protein level. Smoliak and Slen (1974) found gains of 108 kg $ha^{-1}$ using yearling steers, six times that of native range at 18 kg $ha^{-1}$ when grazed continuously. The exemplary gains from RWR have resulted in it becoming a common tame forage throughout the Canadian prairies. Russian wildrye is longer lived than CWG and more drought resistant, and is well adapted to silty-clay soils with high fertility. However, it does best when grown in areas with higher summer than winter precipitation (Sharp Bros. 1997). Smoliak and Dormaar (1985) reported that at Manyberries, Alberta DMY of RWR averaged 601 kg $ha^{-1}$ compared to 872 kg $ha^{-1}$ for CWG. Russian wildrye is difficult to establish and it does not compete well with weeds or a cover crop. Stands are optimally maintained with 35-45 kg $ha^{-1}$ of N fertilizer applied in the late fall or early spring (Sharp Bros. 1997). The recommended seeding rate for RWR is 6.7 kg $ha^{-1}$.

Alfalfa is a widely adapted, productive and the most popular legume grown in the region; it also provides excellent pasture gains and hay. The high crude protein and digestibility of alfalfa result in higher livestock gains on pasture compared to grasses alone. It represents 81% of the tame forages grown in Saskatchewan (Statistics Canada 2001). Even though this legume has been plagued with problems of bloat by livestock when grazed alone, it is commonly used in mixes with grasses. Grass is normally grown in mixtures with alfalfa to provide increased fiber and reduce the risk of bloat. Planting perennial grasses with alfalfa enhances soil stabilization, prevents alfalfa heaving, and ensures continued vegetation cover if alfalfa does not persist (Sheaffer et al. 1997). Mixes of alfalfa and grasses tend to have higher yields and economic returns than grasses alone (Lawerence and Ratzlaff 1985). In the drier regions, CWG and alfalfa mixes are common to prevent bloat. As the alfalfa dies out the CWG is then able to increase. CWG and alfalfa are seeded at 3.4 +1.1 kg ha$^{-1}$, while MBr and alfalfa are seeded at 9 +1.1 kg ha$^{-1}$ (SAF 2005). Mixed grass-legume stands will have alfalfa reseeded into the sod with a drill after being heavily grazed the previous fall, and then sprayed with glyphosate at 5 L ha$^{-1}$ in spring prior to seeding the alfalfa to minimize the competition from the grass (Guide to Crop Protection Saskatchewan 2005). Alfalfa has a short life span, requiring that it be reseeded. However, it has been found to persist for up to 10 years under favorable conditions and good management (Watkins et al. 1914). After two years, crown and upper root rot starts which must be managed or stands will begin to thin and yield and quality will decline (Watkins et al. 1914). AC-Grazeland, a bloat resistant variety of alfalfa, has recently been developed for pasture grazing in western Canada (Iwaasa et al. 2004). However, this variety is shorter lived at about 6 years and it produces less animal gain per hectare than other hay-type alfalfa varieties. In pure stands alfalfa is recommended to be seeded at 4.5 kg ha$^{-1}$ in the Brown soil zone and at 9 kg ha$^{-1}$ in the Dark Brown soil zone.

Native Grasses, when properly managed, can provide a wider variety of nutrients and have comparable livestock gains to tame grasses (Iwaasa and Schellenberg 2005). Complex native grass mixtures (Appendix 2) gave a more balanced diet and increased gains due to being able to provide a broader range of nutrients. The Simple mix was seeded at 9.5 kg ha$^{-1}$; a 1:2 ratio (10 kg ha$^{-1}$) of 11-51-00 fertilizer was used as a carrier to prevent bridging. The Complex mix was seeded at 10 kg ha$^{-1}$ and a 1:2.5 ratio (30 kg ha of 11-51-00). The Simple and Complex mixtures produced 0.64 and 0.78 kg d$^{-1}$, respectively, which as expected is lower or similar to some tame species. Some of the advantages of native grasses are their ability to be long-lived and not needing to be reseeded, whereas tame grasses are traditionally reseeded after their productivity has declined below economic thresholds. Native grasses are cost-effective and require little maintenance, resistance to weed invasion and are environmentally sustainable, thus, they are an environmentally friendly solution (Campbell et al. 1996; Mckague 2004). The main advantages of low-input native grasses are not in production or quality, but in avoiding costs of cultivation for establishment, fertilizer and fertilizer application costs, and absence of depreciation on machinery; however, forage quality is normally lower than for tame species. However, it was found that gains were good on native stands due to the high species richness which provided livestock the opportunity to the select the higher quality plants throughout the growing season (Iwaasa and Schellenberg 2005). Low-input species should be retained on the less productive, poorer lands (Wilson 1996). Native grasses which have evolved under grazing are tolerant of limited grazing. They provide lower production costs and higher profit margins when managed properly (Chan-Muehkgauer et al. 1994).

*Economic analysis*

In order to compare the various pasture systems, their economic performance was evaluated over a 15-year period. Revenues from the sale of the beef produced, together with the costs of fertilizer and forage establishment incurred after the first year were discounted to present value terms using the following formula and a discount rate of 5% (Doll and Orazem 1978):

$$PV = (R_o - C_o) + \sum_{T=1}^{14} (R_t - C_t)/(1+r)^t \qquad \textbf{(Eq.1)}$$

where, PV = Present Value (\$/ha)

$R_0$ = revenue in establishment year ($/ha)
$C_0$ = cost in establishment year ($/ha)
$(R_t - C_t)$ = revenue - cost in given year ($/ha)
r = discount rate (%), and
t = year

Revenues and costs were also summed over the 15-year period (without discounting) to get net total returns. The annual net return values shown in Figure 10 were not discounted, but left in nominal dollars for the purpose of comparing the net income streams.

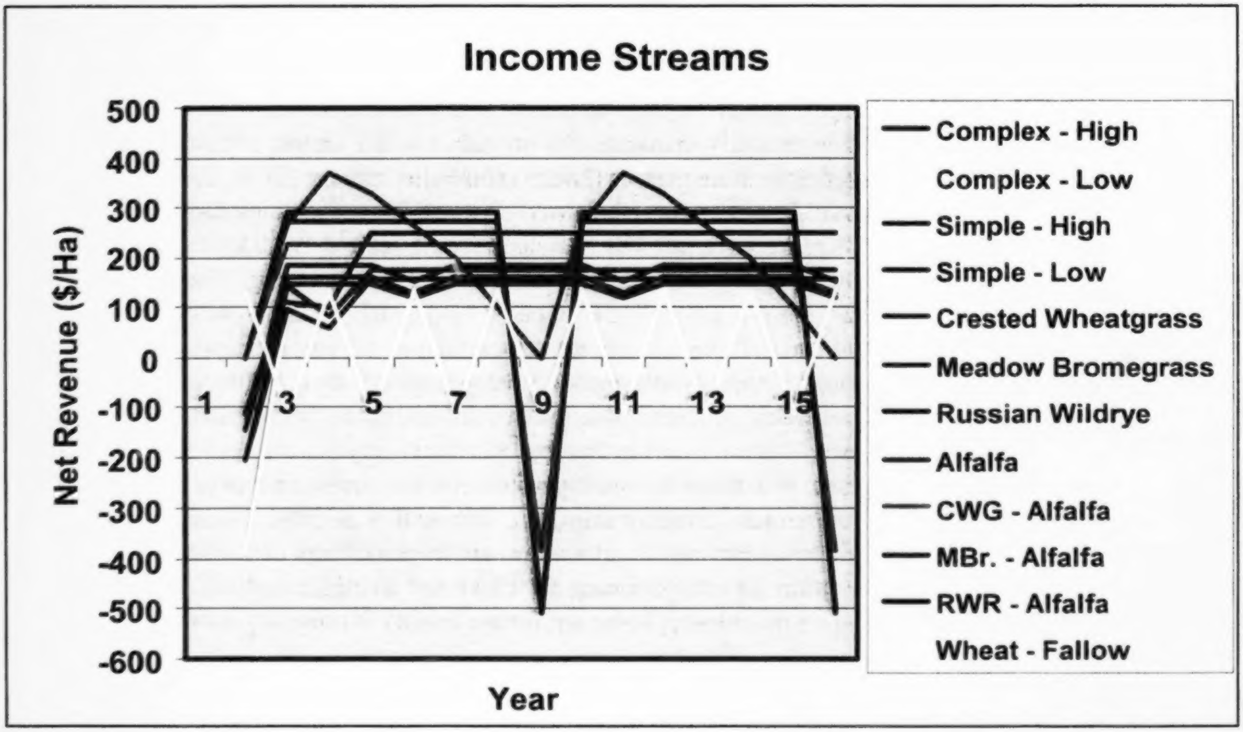

**Figure 10.** Nominal cash flows for different forage/pasture crops (native seed mixtures = simple and complex and pasture utilizations = low (40-50%) and high (60-75%))

*Seed Cost*

One of the main concerns of producers has been the high seed costs for native species compared to tame species. The choice of plant species for a pasture system depends on soil characteristics and landscape, seeding objectives, potential weed invasions, and economic limitations (Jones and Johnson 1998). The lack of a sustained demand has historically limited the supply of new native cultivars, but the growing demand by restorations groups in recent years has lead to more native varieties being developed and greater seed supplies becoming available, which has lowered seed costs. The estimated 2005 cost of seed for natives is significantly higher for the complex mix at $269 ha$^{-1}$ than for the simple mix at $91 ha$^{-1}$. Both native mixes are still much higher cost than for CWG at \$21 ha$^{-1}$ or MBr at \$52 ha$^{-1}$ (Table 9). Alfalfa is often grown in combination with the tame grasses, and is traditionally reseeded into sod every six years to maintain pasture productivity.

**Table 9.** Costs for establishing native and tame pastures (\$ per ha).

| Item cost | Native-complex | Native-simple | CWG | MBr | RWR | Alfalfa | CWG-alfalfa | MB-alfalfa | RWR-alfalfa | Re-seed alfalfa |
|---|---|---|---|---|---|---|---|---|---|---|
| *Seed* | 268.75 | 91.16 | 20.6 | 51.6 | 51.9 | 9.88 | 16.19 | 36.87 | 26.19 | 7.41 |
| *Herbicide* | | | | | | | | | | |
| Roundup original | | | | | | | | | | 44.43 |
| Roundup renew | 6.77 | 6.77 | 6.77 | 6.77 | 6.77 | 6.77 | 6.77 | 6.77 | 6.77 | |
| Buctril M | 14 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14 | |
| Decis insecticide | 6.6 | 6.6 | 6.6 | 6.6 | 6.6 | 6.6 | 6.6 | 6.6 | 6.6 | |
| Sprayer/ apply | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 6.97 |
| Hauling water | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 |
| Sub-total | 52.41 | 52.41 | 52.4 | 52.4 | 52.4 | 52.41 | 52.41 | 52.41 | 52.41 | 55.03 |
| | | | | | | | | | | |
| *Machinery* | | | | | | | | | | |
| Tractor | 10.68 | 4.32 | 4.32 | 4.32 | 2.88 | 4.32 | 4.32 | 4.32 | 4.32 | 1.44 |
| Air seeder | 30.02 | 12.15 | 12.2 | 12.2 | | 12.15 | 12.15 | 12.15 | 12.15 | |
| Drill | | | | | 25.1 | | | | | 25.11 |
| Harrows | 1.33 | 1.33 | 1.33 | 1.33 | 1.33 | 1.33 | 1.33 | 1.33 | 1.33 | |
| Land roller | 3.71 | 3.71 | 3.71 | 3.71 | 3.71 | 3.71 | 3.71 | 3.71 | 3.71 | |
| Labour (\$10 hr$^{-1}$) | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | |
| Trucking seed | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | |
| Trucking fertilizer | 3.63 | 3.63 | 3.63 | 3.63 | 3.63 | | | | | |
| Subtotal | 54.86 | 30.63 | 30.6 | 30.6 | 40.8 | 27 | 27 | 27 | 27 | 32.03 |
| | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Fertilizer* | | | | | | | | | | |
| 11-51-00 | 11.2 | 3.73 | | | | | | | | |
| 46-0-0 & applicator | | | 57.9 | 57.9 | 45.7 | | | | | |
| Sub-total | 11.2 | 3.73 | 57.9 | 57.9 | 45.7 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | |
| **Total cost** | **387** | **179** | **161** | **192** | **191** | **199** | **205** | **226** | **215** | **94** |

Fertilizer costs vary with the pasture system; on the native mixes fertilizer was used only as a carrier to prevent bridging during seeding, while fertilizer was applied periodically to the tames grass pastures. The cost of 11-51-0 fertilizer was \$0.37 kg$^{-1}$. (Iwaasa et al. 2005). It was applied in the establishment year at 10 kg ha$^{-1}$ for the simple mix and 30 kg ha$^{-1}$ on the complex mix. Fertilizer was applied to the monoculture tame grass pastures once every five years at a rate of 57 kg ha$^{-1}$ of 46-0-0 for the CWG and MBr pastures (Thompson et al. 2003) and at 36 kg ha$^{-1}$ of 46-0-0 on RWR. Although it is recommended that RWR be fertilized every year, many producers only fertilize periodically, and only after they see large decreases in forage production or to extend the life of the stand's productive years. Fertilizer was not applied to the grass-alfalfa pasture systems.

### *Expenses and determination of livestock grazing value*

Expenses are based on using the minimum requirements for horsepower, seeding with an air seeder/drill/granular applicator, and then a harrow and a roller to pack. It is estimated that it would take approximately 12 hours of labor and machine operation time to complete 64.75 ha (one quarter section) (Custom Rate Guide 2004). There are, however, differences in the machinery costs among the pasture systems (Table 8).

Beef production gains from the pasture systems were valued at a low, medium and high price of \$1.87 kg$^{-1}$, \$2.20 kg$^{-1}$ and \$2.53 kg$^{-1}$, respectively, for steers (Canfax, 2005). This represents one standard deviation above and below the 10-year mean steer price (1995-2005). The grazing days for cow/calf pairs were valued at \$0.75, \$1.00 and \$1.25 pair$^{-1}$ day$^{-1}$ (Graham 2005 personal communication). Since all data collected were measured as TLP of steers, this was converted to grazing days at 0.75 animal units for steers then to 1.0 animal unit for the cow/calf pair grazing days. It was assumed that beef production leveled off in the 4th year, and was maintained for the rest of the 15- year period at the three-year average. All data were converted to Brown soil zone conditions. For example, 70% of Black soil zone production was used. Opportunity costs of reseeding the legume and grass-legume pastures were taken into account. Since the pastures were assumed not to be grazed in the reseeding year, the cost of the weight gained by the steers and the grazing days for cow/calf pairs, were taken into account using the average production of that sward.

### *Common costs*

It was assumed that seeding costs and management of weeds (e.g., herbicide application) was the same for natives and tame species at approximately \$107 ha$^{-1}$ (Table 9). An air seeder was used at a cost of \$30 ha$^{-1}$; this cost was reduced by \$1.48 ha$^{-1}$ if a granular applicator was used (Custom Rate Guide 2004). Disk drills were used to reseed the RWR. The comparison of native mixes to tame species, the latter having higher production in the first years, was done to see if the additional cost of reseeding resulted in greater production and net returns overall compared to the native pastures (which were not reseeded). Land costs, fencing, and water development to get the area ready for grazing are costs that are common to all treatments, and were thus not included in this analysis.

*Profitability*

The native pastures have more grazing day ha$^{-1}$ compared to the tame grass monocultures; but, the ADG are lower (Table 10). The alfalfa and alfalfa mixes have the greatest grazing days and highest ADGs.

**Table 10.** Production summary of native and tame pasture systems for southwest Saskatchewan (production values in kg ha$^{-1}$ and kg day$^{-1}$).

| | | | | | |
|---|---|---|---|---|---|
| **Complex-High** | SPARC | **CWG** | AAFC-SPARC | **CWG - Alfalfa** | Rogler and Lorenz 1969 |
| TLP | 77 | TLP | 85.0 | TLP | 120.9 |
| ADG | 0.81 | ADG | 1.12 | ADG | 1.28 |
| GD/ha | 115 | GD/ha | 69 | GD/ha | 235 |
| Cow/calf GD | 86 | Cow/calf GD | 52 | Cow/calf GD | 435 |
| **Complex-low** | SPARC | **MBR.** | Thompson etal.2003 | **MBr. - Alfalfa** | Holt and Jefferson 1999 |
| TLP | 55 | TLP | 98 | TLP | 154.3 |
| ADG | 0.70 | ADG | 1.08 | ADG | 0.95 |
| GD/ha | 86 | GD/ha | 82 | GD/ha | 400 |
| Cow/calf GD | 64 | Cow/calf GD | 62 | Cow/calf GD | 741 |
| **Simple-High** | SPARC | **RWR** | Holt 1996 | **RWR - Alfalfa** | Holt and Jefferson 1999, |
| TLP | 67 | TLP | 77 | TLP | 145.3 |
| ADG | 0.71 | ADG | 1.04 | ADG | 0.95 |
| GD/ha | 104 | GD/ha | 74 | GD/ha | 378 |
| Cow/calf GD | 79 | Cow/calf GD | 57 | Cow/calf GD | 702 |
| **Simple-Low** | SPARC | **Alfalfa** | AAFC-SPARC | | |
| TLP | 53 | TLP | 142 | | |
| ADG | 0.49 | ADG | 1.36 | | |
| GD/ha | 126 | GD/ha | 77 | | |
| Cow/calf GD | 94 | Cow/calf GD | 101 | | |

Over the 15-year study period, the annual revenues from the sale of beef products (i.e., steers or calves), together with the costs for pasture establishment and for periodic fertilization and reseeding (where applicable), for each pasture system were discounted at 5% to reflect the time value of money. Overall, the most profitable pasture system at the low price scenario for steers (\$1.87 kg$^{-1}$) was MBr-alfalfa, which earned an average discounted net return of \$2136 ha$^{-1}$ over the 15 years (Table 11). RWR-alfalfa and alfalfa alone ranked second highest with 15-year discounted net earnings of \$1968 ha$^{-1}$, or 8% less than the best system for this same beef price scenario. The CWC-alfalfa pasture system ranked third highest at \$1639 ha$^{-1}$ (23% less), while the monoculture grass pasture systems generally ranked fourth highest at about \$1333 ha$^{-1}$ (38% less). The net earning for the native pasture systems generally ranked lowest (from 54% to 73% less than for MBr-alfalfa), with the high stocking rate for steers (i.e., 60-75% forage utilization) on the native pastures being generally more profitable than the low stock rate (i.e., 40-50% forage utilization).

**Table 11.** Estimated economic performance (15-year discounted costs and net returns ($ per ha)) of different native and tame pastures based on three different price scenarios for steers ($1.87 kg$^{-1}$, $2.20 kg$^{-1}$ and $2.53 kg$^{-1}$) and cow/calf pairs ($0.75, $1.00 and $1.25 pair$^{-1}$ day$^{-1}$).

| | Steers | | | Cow/Calf Pairs | | |
|---|---|---|---|---|---|---|
| **Native mixes** | Low | Med | High | Low | Med | High |
| **Complex-High**[1] | | | | | | |
| NVP returns | 1357.61 | 1597.19 | 1836.77 | 520.67 | 694.23 | 867.78 |
| Total costs | 387.22 | 387.22 | 387.22 | 387.22 | 387.22 | 387.22 |
| Total profit | 970.40 | 1209.97 | 1449.55 | 133.45 | 307.01 | 480.56 |
| **Complex-low** | | | | | | |
| NVP returns | 966.24 | 1136.75 | 1307.27 | 432.88 | 577.17 | 721.46 |
| Total costs | 387.22 | 387.22 | 387.22 | 387.22 | 387.22 | 387.22 |
| Total profit | 579.02 | 749.54 | 920.05 | 45.66 | 189.95 | 334.24 |
| **Simple-High** | | | | | | |
| NVP returns | 1176.33 | 1383.92 | 1591.51 | 498.79 | 665.06 | 831.32 |
| Total costs | 203.16 | 203.16 | 203.16 | 203.16 | 203.16 | 203.16 |
| Total profit | 973.17 | 1180.76 | 1388.35 | 295.63 | 461.90 | 628.16 |
| **Simple-Low** | | | | | | |
| NVP returns | 939.67 | 1105.49 | 1271.24 | 596.27 | 795.03 | 993.78 |
| Total costs | 203.16 | 203.16 | 203.16 | 203.16 | 203.16 | 203.16 |
| Total profit | 736.51 | 902.33 | 1068.08 | 393.11 | 591.86 | 790.62 |
| **Tame grasses and legumes** | | | | | | |
| **Crested Wheatgrass** | | | | | | |
| NVP returns | 1502.07 | 1767.14 | 2032.22 | 370.56 | 494.08 | 617.60 |
| Total costs | 185.69 | 185.69 | 185.69 | 185.69 | 185.69 | 185.69 |
| Total profit | 1316.38 | 1581.45 | 1846.53 | 184.87 | 308.39 | 431.91 |
| **Meadow Bromegrass** | | | | | | |
| NVP returns | 1729.58 | 2034.80 | 2340.02 | 436.78 | 582.37 | 727.96 |
| Total costs | 216.71 | 216.71 | 216.71 | 216.71 | 216.71 | 216.71 |
| Total profit | 1512.87 | 1818.09 | 2123.31 | 220.07 | 365.66 | 511.25 |
| **Russian Wildrye** | | | | | | |
| NVP returns | 1366.24 | 1607.34 | 1848.44 | 401.84 | 535.78 | 669.73 |
| Total costs | 195.09 | 195.09 | 195.09 | 195.09 | 195.09 | 195.09 |
| Total profit | 1171.15 | 1412.25 | 1653.35 | 206.75 | 340.69 | 474.64 |
| **Alfalfa** | | | | | | |
| NVP returns | 2155.00 | 2536.00 | 2916.00 | 634.00 | 845.00 | 1056.00 |
| Total costs | 228.23 | 228.23 | 228.23 | 228.23 | 228.23 | 228.23 |
| Total profit | 1926.77 | 2307.77 | 2687.77 | 405.77 | 616.77 | 827.77 |
| **CWG-Alfalfa** | | | | | | |
| NVP returns | 1873.21 | 2203.78 | 2534.35 | 444.43 | 592.58 | 740.72 |
| Total costs | 234.53 | 234.53 | 234.53 | 234.53 | 234.53 | 234.53 |
| Total profit | 1638.69 | 1969.25 | 2299.82 | 209.91 | 358.05 | 506.20 |
| **MBr.-Alfalfa** | | | | | | |
| NVP returns | 2391.67 | 2813.73 | 3235.78 | 750.94 | 1001.25 | 1251.57 |
| Total costs | 255.21 | 255.21 | 255.21 | 255.21 | 255.21 | 255.21 |
| Total profit | 2136.46 | 2558.52 | 2980.58 | 495.73 | 746.04 | 996.36 |
| **RWR-Alfalfa** | | | | | | |
| NVP returns | 2252.20 | 2649.64 | 3047.09 | 704.96 | 939.95 | 1174.94 |
| Total costs | 244.53 | 244.53 | 244.53 | 244.53 | 244.53 | 244.53 |
| Total profit | 2007.66 | 2405.11 | 2802.56 | 460.43 | 695.42 | 930.41 |

[1] Complex = 14 native species, Simple = 7 native species, High 2.7 AU ha$_{.1}$ or 60-75% pasture utilization and Low = 1.3 AU ha$^{-1}$ or 40 to 50% pasture utilization.

Increases in the market price for steers further improved the economic performance of the legume and grass-legume pastures relative to the native pastures (Table 11). For example, it would take about 22 years before the discounted net returns earned with the complex native mix at the high stocking rate to surpass the net earnings from RWR (the poorest performing tame monoculture grass system), and it would take more than 50 years for the simple native mix at the high stocking rate to surpass the net returns earned with monoculture MBr (the best performing tame monoculture grass system). These results indicate that the tame pasture systems, particularly the grass-legumes mixes, provide significantly higher economic returns than the natives systems, except in the very long term. However, with the current Federal support (i.e., Greencover program) of \$247 ha$^{-1}$ being offer to offset the cost of seeding natives and the fact that seed costs will continue to decline as demand and seed supplies improve, the number of years needed to breakeven should decline significantly. In addition, other potential revenue benefits (C sequestration and C credits) and Federal assistance to improve and/or maintain an environmental sustainable agricultural practice will provide additional opportunities for innovative livestock producers to consider the use of native species.

The results for the cow-calf pairs differed somewhat from those for steers (Table 11). The most profitable systems at the low grass rental fee of \$0.75 pair$^{-1}$ d$^{-1}$ were again the MBr-alfalfa and RWR-alfalfa pasture systems (average discounted net earning of \$478 ha$^{-1}$), with alfalfa alone and the simple native mix at the low stocking rate ranking second highest with average net earnings of about \$400 ha$^{-1}$ (16% less). The simple native mix at the high stocking rate ranked third highest at \$295 ha$^{-1}$, while CWG-alfalfa and the monoculture tame grass pastures ranked fourth highest. The least profitable pasture systems for cow-calf pairs were the complex native mixes. The weakness of this analysis is that by using a grazing rent it does not take into account the increased calf gains from the better quality forage. It is these extra pounds the producer sells in the fall which results in increased revenue that is not seen in this analysis.

The decrease in native seed costs, combined with the incentive programs, has improved the economic feasibility of establishing native pastures on marginal crop land. In doing this, there is no greater risk in establishment or production, compared to other tame species that have historically been favored for this type of seeding. Overall, our results suggest that the most profitable pasture system was MBr-alfalfa for grazing both steers and cow-calf pairs, but with RWR-alfalfa being a close second. The complex native mix pasture system when used for grazing steers at a high stocking rate (i.e., 2.7 AU ha$^{-1}$) was approximately economically competitive with RWR monoculture (when one includes the incentive programs), but it was not generally economically competitive with the tame grass-legume mixes. And for cow-calf pairs, our results suggest that the simple native mix at the low stocking rate (i.e., 40-50% forage utilization) was typically more profitable than the monoculture tames grass pastures and CWC-alfalfa, and was generally comparable in net earnings to alfalfa alone. However, native grasses are most desirable to be grazed later in the summer or fall and would not be appropriate if a producer was looking for early spring grazing. Forage yield is not the only consideration since other attributes can be equally important (Wilson 1996) such as lengthening the grazing season into the fall to save feeding costs, environmental benefits such as decreased erosion, carbon sequestration and increased biodiversity, and increased livestock gains due to cattle being able to select species that better fill their requirements in a heterogeneous plant stand. Research is ongoing into selecting the best combinations of native grasses and native legumes or tame legumes to grow in different pasture mixtures to not only improve the nutrition of the forage and cattle performances but also to aid in N cycling, increase environmental sustainability and improve C sequestration potential of these lands. It is estimated in western Canada that between 7 to 11 million ha of land is annually cultivated but is economically unprofitable and environmentally unsustainable (AAFC-PFRA 2000), and much of this land should be put into perennial forage in which the use of native species can provide an important sustainable grazing resource and with substantial environmental benefits.

## Conclusions

Study results showed that a Bourgault double disk air seeder was successful in seeding a native mixture of native species into standing stubble, however, careful monitoring of the seeding is needed to ensure a uniform flow of seed and prevent seed bridging problems which can result in skips and seeding misses. Of the fourteen grass, forb and shrub species seeded, only JG and saltbush were not observed in the pastures during the seeding year, however, JG was observed later in following years. Wheatgrasses, GNG, NTG, BG, LBS, PPC were commonly observed in the seeding year. In contrast to previous research conducted at AAFC-SPARC, establishment of warm season grasses was not a problem. Effective pre and post-plant weed controls prior to seeding provided adequate weed suppression to promote successful native establishment past the 2001 drought period.

Study results found that the average SOC level for the cultivated land (crop-fallow rotation for 80+ years) in 2000 was about 28 Mg C $ha^{-1}$ and in four short years under a native perennial grazing system about 2.12 Mg C $ha^{-1}$ was sequestered. This represents about 530 kg C $ha^{-1}$ $yr^{-1}$ being sequestered in the semiarid Brown soil area of the province. This is quite remarkable since average reported C sequestration rates for crop land converted to perennial grasses after 10 years have been 100 to 800 kg $ha^{-1}$ $yr^{-1}$. Clearly the favourable moisture received during the research study, producing good native forage biomass and the depleted level of SOC in the soil has greatly assisted in the amount of soil C that was sequestered. The simple native seed mix under high pasture utilization gave the highest ($P < 0.05$) SOC level compared to the other seed mixture and pasture utilization combinations. Higher SOC associated with the simple seed mix under high versus low pasture utilization treatments may be due to more livestock hoof action breaking down and incorporating the standing dead and litter into the soil and enhancing decomposition and reducing loss through oxidation. The generally higher SOC associated with the simple seed mixture can be mostly explained by the higher accumulation of biomass productivity (above and below ground) associated with the simple seed mixture, especially during the first year of pasture production, which would be a major factor influencing SOC production. In agreement, higher ($P = 0.01$) mean SOC values for the simple compared to the complex native seed mixture were found and the values were 2.53 and $1.48 \pm 0.83$ Mg C $ha^{-1}$, respectively. Mean SOC measurements did not differ ($P > 0.29$) between grazed and ungrazed treatments. These results are in contrast to a number of other research studies that have reported a benefit to grazing and higher grazing pressure on increasing soil C. However, it is too soon yet to determine potential SOC differences between grazing and pasture utilization treatments in the four years that have occurred. As expected, mean microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial dehydrogenase activity values were higher for treatments that corresponded to the higher biomass production and C sequestration levels. Results from this study shows evidence that the resident soil microbial population under a previous annual cropping system (80+ yrs) can continue to subsist and adapt and expand in a perennial native forage system quickly. Because the native pastures are still evolving and undergoing changes there is the need to further evaluate the microbial characterizations of the native soils in the future to determine their effects on SOC.

The highest forage biomass among the four production years was observed for the simple versus the complex seed mixture in 2002. This was expected since the wheatgrass species made up a higher proportion of the simple (i.e., 61%) compared to the complex seed mixture (30%). Unexpectedly available forage productions between the two native mixtures did not differ ($P > 0.05$) after 2003 and a steady forage production state may have been reached. Higher ($P < 0.05$) available forage yields were observed for the simple seed mix under low compared to high pasture utilization. Differences in grazing pressure and shifts in individual plant species due to grazing may provide another explanation for forage yields differences over the four years of production. The ability of the complex native mix to have forage yields that did not differ ( $P > 0.05$) between the two pasture utilizations could be a result of the increase biodiversity existing in the complex pasture (i.e., cool and warm season grasses) and thus providing more flexibility in the plant community to adapt to the grazing treatments. Higher ($P < 0.05$) available forage production for the simple versus the complex native seed mix under a low pasture utilization was not surprising since the simple mix contained more aggressive and higher producing wheatgrasses while the complex mix contained other grasses with a slower onset of growth for the pasture study (e.g., warm season grasses).

All available forage quality measurements were significant ($P < 0.0001$) for year effects. The wet and cloudy growing conditions and higher soil fertility observed in 2002 compared to the other years is a possible explanation for the lower %OMD and higher %ADF, %NDF and %CP observed. Higher ($P < 0.05$) NDF value was observed for the complex versus the simple seed mixture while all other forage quality's measurements did not differ for forage biomass harvested just before the cattle started grazing (i.e., spring season). However, better nutritional forage qualities for the complex versus the simple native mixes were observed as the grazing season extended into the summer and fall season.

Significant ($P < 0.0001$) year effect occurred for average daily gain (ADG) and total live production (TLP) and year 2003 had the lowest ($P < 0.001$) ADG and TLP values compared to the other two years (2002 and 2004). The ADG values for 2002 and 2004 were similar, while the TLP value for 2004 was the highest ($P < 0.05$) due to the favourable moisture condition and extended grazing season that occurred. Although not significant ($P = 0.12$), the overall ADG mean for the complex mix was higher than the simple mix. These results correspond to about a 26.6% overall improvement in ADG for yearling steers grazing on the complex compared to the simple native pastures through the grazing season. It is plausible to expect better steer grazing performance on the complex pastures due to the higher specie richness (i.e., different mixture of warm and cool season grasses and shrubs) that would improve the nutritional composition of the pasture through the entire grazing season (spring to fall). The trend ($P = 0.14$) for higher ADGs for steers grazing at the higher compared to the low pasture utilization level was also observed, which was probably due to higher degree of forage selection and regrowth potential. Throughout the research study, different grazing behaviours for the yearling steers were observed on the different native pastures throughout the grazing season. During the spring and early summer period of grazing the cattle have no difficulty grazing and selecting for CWR, AWG, SWG, NTG, GNG, NWG and WWG species. Once the grazing period reached mid summer, many of the cool season grasses were at heading and seed setting. At this time the steers on the complex native pasture selectively grazed the warm season grasses, PPC (even at the heading/seed stage) and regrowth areas from cool season grasses. In the fall grazing season, cattle continued to select for warm season grasses, however, once heading and seed setting had occurred the steers grazed these grasses less and less and appeared to start grazing NTG, GNG, NWG and WWG. Fall grazing preference of the warm season grasses in our study was observed to following this ranking LBS $\geq$ PSR > BG. The observed grazing preferences shown by yearling steers for our research studies are very much dependent upon what plant species are available for them to choose from and the grazing management.

The 2004 data for the large pastures continues to indicate the grazing impact on species richness. Grazed vegetation had greater diversity than the ungrazed. The species within the ungrazed are changing but continue to be dominated by the wheatgrasses. NWG decreased in dominance while

WWG increased. Northern wheatgrass and SWG appear to function as early seral species with an initial flush with eventual replacement with slower growing later seral species, in this case WWG and LBS. Purple prairie clover also increased over time. The complex seed mix was 97% wheatgrasses but the wheatgrasses made up only 66% of the complex mix. There was an increase in the warm season grasses, BG and LBS, and PPC. This may have been in part due to the more open canopy due to grazing. Weed content was insignificant after three years.

The date of seeding effects were evident throughout the three years of growth for both small plot studies. Green needle grass contributed more to the plot composition throughout all years if seeded in late fall. Slender wheatgrass showed a similar trend but only when seeded in early spring. The hot dry year of 2003 greatly decreased establishment for both small plot studies. The seral stages studies clearly demonstrated the advantage of fall seeding for all species. This result is something which should be considered if future climate change scenarios, which indicate a drier environment for southern Saskatchewan, are valid.

Both small plot studies showed an increase in similarity with minor changes in species richness. These changes possibly reflect the impact of the single fall harvest regime. This single fall harvest allowed the wheatgrass to out compete the slower growing species closing the canopy. Species richness is also less than values calculated for the grazed pastures further indicating the benefit of grazing disturbance in retaining species diversity.

The ungrazed enclosures in the pastures do not show the same trend seen in the small plots. In the ungrazed enclosures there is an increase in rhizomatous species, western wheatgrass and little blue stem. This may reflect the impact of having a grazing disturbance immediately adjacent to a relatively small ungrazed remnant. Grazing may increase the competitive advantage of the rhizomatous species outside the enclosure resulting in an invasion of the area within the enclosure by these species.

Seeding species by seral classification affects certain species. Northern wheatgrass, GNG and SWG appear to benefit from seeding in this fashion. Other species may benefit but the strongly contrasting environmental conditions between years may have concealed any potential benefits.

The decrease in native seed costs, combined with the incentive programs, has improved the economic feasibility of establishing native pastures on marginal crop land. In doing this, there is no greater risk in establishment or production, compared to other tame species that have historically been favored for this type of seeding. Overall, our economic analyses suggest that the most profitable pasture system was MBr-alfalfa for grazing both steers and cow-calf pairs, but with RWR-alfalfa being a close second. The complex native mix pasture system when used for grazing steers at a high stocking rate was approximately economically competitive with RWR monoculture (when one includes the incentive programs), but it was not generally economically competitive with the tame grass-legume mixes. And for cow-calf pairs, our results suggest that the simple native mix at the low stocking rate was typically more profitable than the monoculture tames grass pastures and CWC-alfalfa, and was generally comparable in net earnings to alfalfa alone. Other potential benefits from environmental sustainable agricultural practices (C sequestraton/C credits, environmental farm plan etc.) may also provide financial incentives that would see more annual crop land converted into native pastures.

This research study has clearly shown that it is possible to re-establish a mixed native grassland in southwest Saskatchewan without the use of specialize seeding equipment. Differences in the native species mixture (i.e., simple or complex) can affect animal grazing performances and C sequestration potential. Although grazing is a natural phenomenon, to which grasslands are well adapted, this disturbance did affect how the native stand established and specie richness, especially when compared to an ungrazed system. This study showed the ability of a more diverse native mix over time to have similar or better forage and beef production compared to the simple mix because of a niche complementarity among species. Higher than expected C sequestration and MBC, MBN etc. potentials were observed within a four-year period for the re-established native pastures. Date of seeding and seeding species by seral classification were beneficial for certain species (GNG, SWG etc.) and these results are something to consider if future climate change scenarios of a drier environment for southern Saskatchewan occurs. Results indicate that a complex native mix could compete with a tame grasses and alfalfa mix, and a simple native mix could compete with a tame species, especially with decreasing native seed costs and combine with different federal incentive programs. The best economical use of native pasture would be for a cow/calf grazing system. However, using different grazing systems (complementary, rotation etc.) on native pastures can greatly extend the grazing season and make the economic feasibility of establishing native pastures on marginal crop land more beneficial. Unfortunately, the relatively short period of the study may have mitigated the detection of various treatment effects and it is acknowledged that native plant communities are still evolving, therefore, additional and future evaluation of this research study should continue. Additional funding has been secured thanks to the support of many of the same research partners we had previously, thus this study will continual for another four years in which many of the current objectives and new objectives will be evaluated. The new research project is titled "Effect of different grazing systems on forage and beef production and their contribution to soil and air quality."

**Information presented as a result of this research study**

*Workshops and conferences*

Invited presentations at the 2002 Western Canadian Grazing Conf. ("Selecting introduced and/or native perennial forages to extend your grazing season"December 4-6, 2002), Tame and Native Workshop by SWA and DUC ("Forages and grazing strategies for the semiarid brown soil area of Saskatchewan" May 13, 2003), Plain as the Eye Can See, Managing Changing Prairie Landscapes Conf. (Re-evaluation of native plant species for seeding on the semiarid prairie of western Canada" May 17, 2003), Native Plant Summit VII: Planning Native Landscapes -Urban and Rural ("Forage and grazing potential of a newly re-established mixed grassland in southwest Saskatchewan" Sept. 16-18, 2003), Semi-arid Native Grassland Restoration Workshop ("Re-establishment of native grassland species" Sept. 24, 2003), Western Canadian Forage and Grazing Conference ("Successful forage establishment requires proper planning and seeding preparation and the selection of the right forage species" December 3-5, 2003), Native Plant Society of Saskatchewan annual general meeting (February 5-7, 2004), 7th Prairie Conservation and Endangered Species Conference ("Forage and grazing potential of a newly re-established mixed grassland in southwest Saskatchewan" February 26-29, 2004), 2004 Canadian Society of Agronomy Annual Meeting ("Impact of changing annual environmental conditions on native forage species" July 20-22, 2004), Foraging into the Future III: Moving beyond uncertain times ("Establishing a mix native grassland in southwest Saskatchewan: what have we learned?" December 14-15, 2004), Society of Range Management 56th Annual Meeting ("Improved grazing production between two seeded native pastures in Saskatchewan due to species richness differences" February 6-11, 2005), Manitoba Grazing School 2005 ("Re-establishment of native species in western Canada: secrets on improving grazing efficiency with environmental benefits"December 7-8, 2005), Native Seed Workshop ("Successful establishment of native forages on annual crop land" December 14, 2005), Southwest Forage Association Annual Meeting 2006 ("Can we grow natives for grazing in Saskatchewan?" Jan. 12, 2006) and Society of Range Management 57th Annual Meeting ("Effect of increase biodiversity on grazing performance of different native pasture mixtures seeded in southwest Saskatchewan in 2001" Feb. 12-17, 2006).

*Industry workshops*

Agricore United/Proven Seed

Invited speaker, Regina ("Native species:forage and grazing potential in southwest Saskatchewan" March 9, 2004).

Invited speaker, Edmonton ("Native species: forage and grazing potential in Alberta and Saskatchewan" February 17, 2005).

*Media transfer*

Several radio interviews with CKSW (Swift Current) on native research in 2002, 2003, 2004 and 2005.

Radio interview with CMOS (Brandon) on native research in 2005.

Interview by the Prairie Farm Report and telecasted on Dec. 3rd, "Grazing management strategies on recently re-established native grasslands."

*Technology transfer articles*

Article in the Cattlemen "Using Native Plant Species for Profitable Pasture Production" (March, 2003).

Manitoba Agriculture and Food article "Native verses Introduced Plant Species: Which One Should I Consider for my Next Pasture Expansion?" (Manitoba Beef Review Vol. 3, issue 1. 2003)

Greencover Canada Conversion Component Toolkit of References for Tame and Native Forages

AAFC-PFRA "Selecting Introduced and/or Native Perennial Forages to Extend your Grazing Season."

Article in the Native Plant News: Seed and Restoration Special Edition, 2003, "The Challenges of Re-establishing a Mixed Native Grassland in Southwest Saskatchewan."

Article in Range and Pasture Management 2004, "Grazing for profit."

Article in the Saskatchewan Livestock and Forage Gazette 2004, "Are Native Plant Species a Seeding Option?"

2004 Seed Guide article "Re-establishment of native Species."

Article found on the Canadian Cattleman's Association - Greenhouse Gas Mitigation Program, Meristem Information Resources, October 2004, "Back to the future with native grass prairie" http://www.jpcs.on.ca/biodiversity/ghg/news/f-2004-12-02.html

Article in the Prairie Post "Iwaasa back to the future with native prairie grasses" on Feb. 18, 2005.

Interview for the Cattlemen article "Native grass blends raise eyebrows" (May 2005). Article appeared in the June/July Canadian Cattlemen pgs. 28-29.

Article in the Saskatchewan Livestock and Forage Gazette 2005, "Seeding of native species in southwest Saskatchewan can it be done?"

*Tours*

In 2002 three tours were organized in which a total of 120 participants viewed the native research study.

In 2003 three tours were organized in which a total of 70 participants viewed the native research study and were provided with information sheets.

In 2004 three tours were organized in which a total of 110 participants viewed the native research study and were provided with information sheets.

In 2005 three tours were organized in which a total of 105 participants viewed the native research study and were provided with information sheets.

*Previous and continuation of research study with partnerships*

**Project title** "Assessment of grassland management and restoration practices on the availability and quality of insects as food for grassland species at risk" Interdepartmental Recovery Fund (funding obtained 2003/04) and partnerships: IRF-FIR, U.of Lethbridge, Grasslands National Park, AAFC-SPARC and CFB Suffield.

**Project title** "Effect of different grazing systems on forage and beef production" Federal matching investment initiative and industry/producer cash and in-kind contribution (funding obtained 2004/05) and partnerships: SWFA, Proven Seed, Nexen Inc., Native Plant Solution, DUC and SE.

**Project title** "Greencover native grasses-legume mixes" Federal Greencover and industry/producer cash and in-kind contribution (funding obtained 2005) and partnerships: SWFA, DOW and AAFC.

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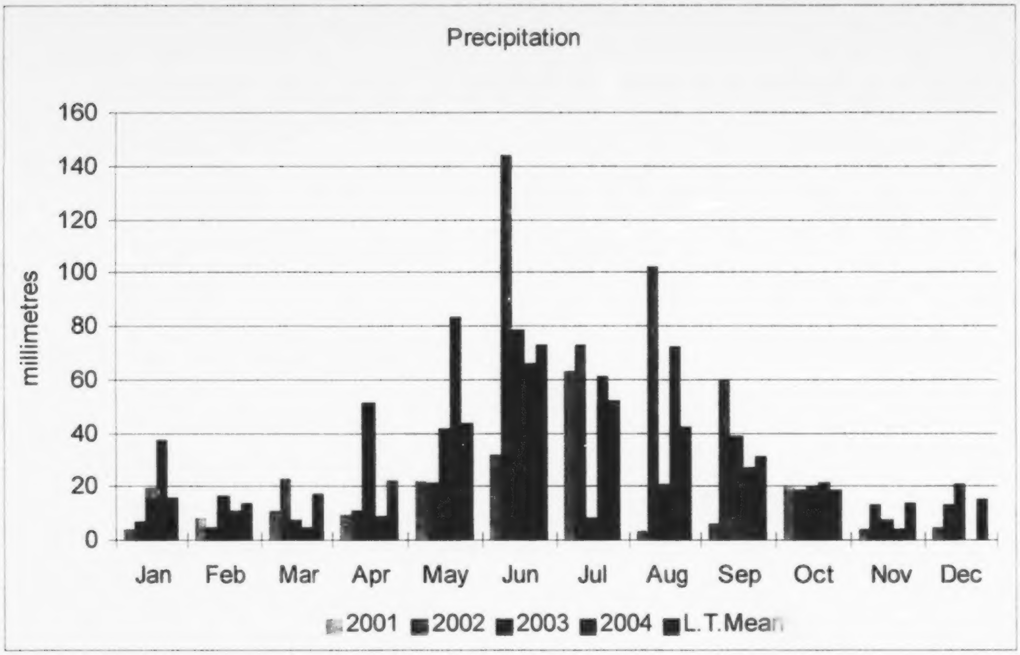
# Appendix 1



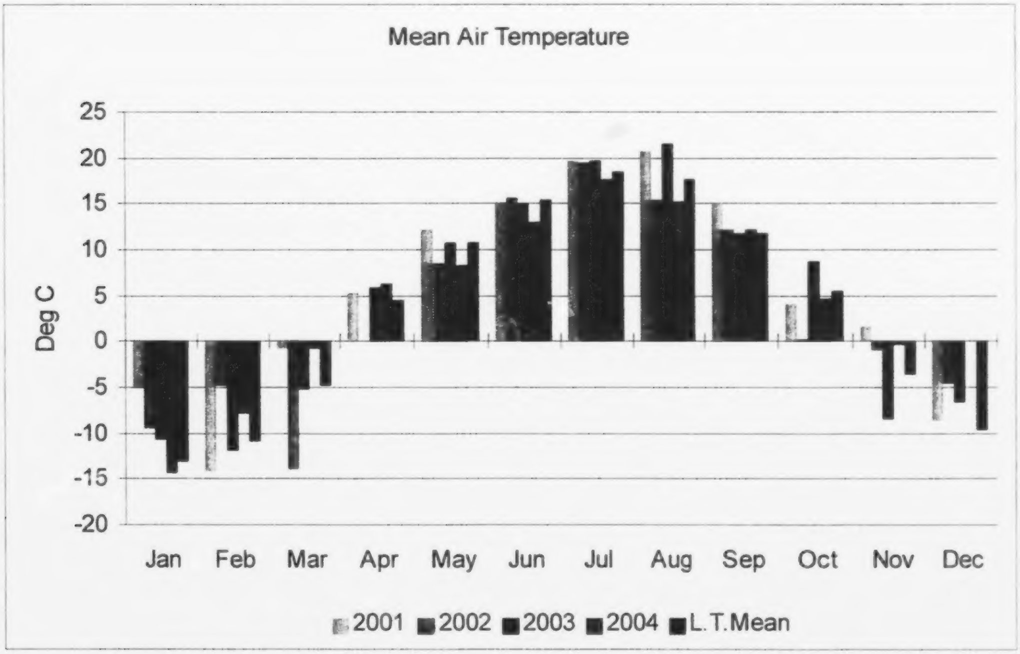


**Figure 1.** Mean air temperature and precipitation values for 2001 to 2004 compared to the long term averages (116 years).

## Appendix 2

**Table 1.** Specie mixtures for the two native mixtures (simple or complex) that were formulated by Native Plant Solution - Ducks Unlimited Canada (contact information - NPS - DUC, 1255B Clarence Ave, Winnipeg, MB., R3T 1T4).

**Simple mix**
Western wheatgrass (WWG)
Northern wheatgrass (NWG)
Green needle grass (GNG)
Awned wheatgrass (AWG)
June grass (JG)
Slender wheatgrass (SWG)
Purple prairie clover (PPC)

**Complex mix**
Western wheatgrass
Northern wheatgrass
Green needle grass
Awned wheatgrass
June grass
Slender wheatgrass
Purple prairie clover
Canada wildrye (CWR)
Little bluestem (LBS)
Needle and thread grass (NTG)
Blue grama (BG)
Prairie sandreed (PSR)
Saltbush (SB)
Winterfat (WF)

**Early seral mix**
Slender wheatgrass
Awned wheatgrass
Purple prairie clover
Saltbush
Winterfat

**Late seral mix**
Western wheatgrass
Northern wheatgrass
Needle and thread grass
June grass
Green needle grass
Blue grama
Prairie sandreed

**Grasslands National Park supplied forbs**
Two-grooved milk-vetch (*Astragalus bisiculatus*)
Narrow leaf milk-vetch (*Astragalus pectinatus*)
Gaillardia (*Gaillardia aristata*)
Dotted blazing star (*Liatris punctata*)
Early yellow locoweed (*Oxytropis sericea*)
Coneflower (*Ratibidia columnifera*)
Golden bean (*Thermopsis rhombifolia*)

**Table 2.** Seral stage study treatments.[1]

| Plot | Treatments |
|---|---|
| 1 | Fall seeded - complex mix |
| 2 | Fall seeded - simple mix |
| 3 | Fall seeded early seral + late seral seeded 1 yr later |
| 4 | Fall seeded early seral + late seral seeded 2 yr later |
| 5 | Fall seeded early seral + late seral seeded 3 yr later |
| 6 | Fall seeded late seral + early seral seeded 1 yr later |
| 7 | Fall seeded late seral + early seral seeded 2 yr later |
| 8 | Fall seeded late seral + early seral seeded 3 yr later |
| 9 | Spring seeded - complex mix |
| 10 | Spring seeded - simple mix |
| 11 | Spring seeded early seral + late seral seeded 1 yr later |
| 12 | Spring seeded early seral + late seral seeded 2 yr later |
| 13 | Spring seeded early seral + late seral seeded 3 yr later |
| 14 | Spring seeded late seral + early seral seeded 1 yr later |
| 15 | Spring seeded late seral + early seral seeded 2 yr later |
| 16 | Spring seeded late seral + early seral seeded 3 yr later |

[1] treatments replicated 4 times and plot size was 2 x 8 m.

**Table 3.** Optimum date of seeding study treatments.[1]

| Plot | Treatments |
|---|---|
| 1 | Complex mix - Fall seeded (late September within 1-2 d of 12.5 mm of rainfall) |
| 2 | Complex mix - Fall seeded (October after soil temperature is below 5°C) |
| 3 | Complex mix - Spring seeded (late April/early May within 1-2 d of 12.5 mm of rainfall) |
| 4 | Complex mix - Spring seeded (late May within 1-2 d of 12.5 mm of rainfall) |
| 5 | Complex mix - Spring seeded (June 21) |
| 6 | Complex mix - Spring seeded (after June 21st within 1-2 d of 12.5 mm of rainfall) |
| 7 | Simple mix - Fall seeded (late September within 1-2 d of 12.5 mm of rainfall) |
| 8 | Simple mix - Fall seeded (October after soil temperature is below 5°C) |
| 9 | Simple mix - Spring seeded (late April/early May within 1-2 d of 12.5 mm of rainfall) |
| 10 | Simple mix - Spring seeded (late May within 1-2 d of 12.5 mm of rainfall) |
| 11 | Simple mix - Spring seeded (June 21) |
| 12 | Simple mix - Spring seeded (after June 21st within 1-2 d of 12.5 mm of rainfall) |

[1] treatment replicated 4 times and plot size was 2 x 8 m.